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Chemical Equilibria in Water Treatment

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A contribution to the Journal

IN an earlier paper (1) in 1936, the author proposed the saturation index as a means of indicating, from readily obtained analytical values, the tendency of natural or conditioned waters either to deposit or dissolve calcium carbonate when brought into contact with this substance. Prior to this time, Tillmans and collaborators (2), in a series of papers published between 1912 and 1932, had recognized the importance of carbonate scale in protecting the interior of water pipes against corrosion and had developed the well-known marble test as a basis for formulating this equilibrium. Their formulation, however, was limited to waters containing measurable quantities of free CO_2 and accordingly could not be applied to natural and conditioned waters of moderately high pH.

Several articles (3, 4, 5, 6 and 7) relating to the saturation index, which have since appeared, indicate a wide interest in the subject. The dependability of results predicted by the saturation theory has not been always favorable and perhaps it would be fair to state that the index and its associated pH_s value are generally accepted with a degree of reservation. However, interest in the subject has not abated and the limitations of the theory are beginning to be better understood. It is believed that, with continued research and the correlation of theory with practice, the earlier estimates of its value will prove justified. To this end there exists a definite need in the direction of standardization in the selection of constants and in the application of temperature and salinity corrections. The following paper on the temperature coefficient of pH, together with this paper, it is hoped, will be regarded not as reviews of the subject but as efforts toward standardization and to the extension of the original discussion to include a consideration of additional equilibria involved in the lime process of softening and in certain other methods of water treatment.

The basic reaction involved in the reversible pipe scaling process can be written:

$$CaCO_3 \text{ (solid)} + H^+ \rightleftarrows Ca^{++} + HCO_3^- \quad (1)$$

At equilibrium, therefore, the product of the molal concentrations of calcium and bicarbonate divided by the molal concentrations of hydrogen ion will remain constant, or

$$\frac{[Ca^{++}] \times [HCO_3^-]}{[H^+]} = k \quad (2)$$

Expressing each term in negative logarithms we can write for the pH at equilibrium

$$pH_{eq.} = pCa^{++} + pHCO_3^- - pk \quad (3)$$

In the earlier reference cited (1) it was shown that $pHCO_3$ at all pH levels can be formulated in terms of pH and total alkalinity. It was also shown that the $-pk$ term of Eq. (3) is actually the difference between pK_2, the ionization constant of the acid HCO_3^-, and pK_s, the solubility product constant for calcium carbonate. Since the values of these two constants are known it was possible to formulate the basic reaction (1) in terms of readily obtained values, which was given as follows:

$$pH_s = (pK_2 - pK_s) + pCa^{++} + p\left[\text{Alky.} + [H^+] - \frac{K_w}{[H^+]}\right] + \log\left[1 + \frac{2K_2}{[H^+]}\right] \quad (4)$$

By definition the saturation index was written:

$$\text{Saturation Index} = pH - pH_s \quad (5)$$

Equation (4) is believed to be an accurate expression of the calcium carbonate equilibrium, applicable for the purpose intended, and its value in practice is limited only by the accuracy of the analytical data and the values of the constants employed.

Although magnesium salts are not commonly found in pipe incrustations, the extension of the data to water softening requires consideration of the solubility of magnesium hydroxide. For this equilibrium we can write:

$$[Mg^{++}] \times [OH^-]^2 = K_{s(Mg)} \quad (6)$$

By combining this equation with the equation representing the dissociation of water and using the notation as above, we can write:

$$pH_{s(Mg)} = \tfrac{1}{2}\left[pMg - pK_{s(Mg)}\right] + pK_w \quad (7)$$

It will be noted that Eqs. (4) and (7) contain few variables and that it should be possible to obtain a direct solution of either equation on a simple rectilinear diagram. For this purpose Eq. (4) is written in the form:

$$pCa_s = pH - pHCO_3^- - (pK_2 - pK_s) \quad (8)$$

where:

$$pHCO_3 = p\left[\text{Alky.} + [H^+] - \frac{K_w}{[H^+]}\right] + \log\left[1 + \frac{2K_2}{[H^+]}\right] \quad (9)$$

Values of $pHCO_3^-$ corresponding to several values of alkalinity at varying pH levels are plotted so as to indicate corresponding values of pCa_s. If in such a diagram there are included similar provisions for solving the two dissociation equations for carbonic acid, i.e.,

$$pCO_2 = pHCO_3 + pH - pK_1 \quad (10)$$

and

$$pCO_3 = pHCO_3 - pH + pK_2 \quad (11)$$

the diagram can be used for the rapid solution of a variety of problems involving these equilibria. Such a diagram is shown in Fig. 1. Actually, it is a solubility diagram for calcium carbonate and magnesium hydroxide in dilute carbonate solutions, based upon solubility product considerations. Since, however, its use in practice is intended to indicate actual departures from theoretical values of ultimate equilibrium, we have called it a "stability diagram." *

Description and Uses of the Stability Diagram

The diagram shown in Fig. 1 is limited for use at 25°C. and can be used without salinity correction for natural waters containing from about 200 to 1,000 ppm. of total solids. It furnishes a direct reading of pH_s, as expressed in the long form of the saturation equation, Eq. (4), which is applicable without correction at the higher pH levels. It gives also the corresponding value of pH_s for magnesium, as expressed in Eq. (7). By means of simple graphic interpolation the diagram enables the rapid calculation of total scale-forming or scale-dissolving capacity. Heretofore, these values, as well as the pH which a water will attain at complete stability, have been obtained only by laboratory experiment. Laboratory test procedures vary from the simple marble test (11) to the more elaborate method of direct weighing employed by Ryznar (6). Other methods by McLaughlin (8) and Moore (9) have been described. All are time consuming and several investigators have indicated experimental difficulties.

Plotting of the carbonate equilibria has brought to light a new aspect in the use of the index at high pH levels; namely, that its customary significance is altered if the actual pH of the sample exceeds approximately 10.0, i.e., the average turning point of the calcium carbonate equilibrium lines. Above this level of pH the water may contain calcium hydroxide which is not involved in the stability of the sample. Of the two possible values of pH_s, only the lower value is valid, and, accordingly, it is suggested that in calculating the saturation index (S.I.) when the actual pH of the sample exceeds 10.0, the formula $S.I. = 10.0 - pH_s$ be used. This rule limits the magnitude of a plus index at high pH levels and in part may explain the apparent anomalous behavior of certain lime-softened waters with respect to scale formation.

It is believed that diagrams of the type shown, constructed for use at different temperatures, should prove useful not only in the control of scaling and pipe corrosion but in a variety of problems encountered in hot and cold lime-soda softening, selective softening (10), the de-carbonation of boiler waters (11), etc. Stoichiometric methods of calculation now used in water softening are based upon several false assumptions. The assumption, for example, that magnesium will not precipitate until enough lime has been added to react with all of the bicarbonate present is not in accord with theory, as can be readily inferred from the diagram. An advantage of the equilibrium method of calculation is that by its use plant performance can be related to a theoretical ideal and thereby enable a better evaluation of plant design or operating skill.

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* Editor's Note: Working forms of both the 25°C. and the 75°C. stability diagrams, for laboratory use, are available in large reprint size at 10 cents each from the A.W.W.A. office.

TABLE 1

Examples in the Use of 25°C. Stability Diagram

(All concentrations except pH expressed in mg./l. (ppm.) of equivalent $CaCO_3$.)

1. *Assume:* Alky. 50, pH 10.3. Find the concentration of hydroxide, carbonate and bicarbonate alky.
Solution: Read directly from diagram: hydroxide alky. 12.5; carbonate alky. 28. Bicarbonate alky. by difference = 9.5.

2. *Assume:* Alky. 100, pH 9.0. Find concentrations of the three forms of alky. and also free CO_2.
Solution: To obtain hydroxide alky. read directly concentration at pH 10 and divide by 10. Result 0.6 ppm. Carbonate alky. = 12.5. Bicarbonate alky. by difference = 87. Free CO_2 is less than 1.0. Find exact value by reading value at pH 8.0 and dividing by 10. Result 0.4.

3. *Assume:* Ca 35, alky. 100, pH 8.8. Find pH_s, S. I. and saturation excess or deficit.
Solution: pH_s equals 8.3, S. I. = +0.5; water contains 8.4 ppm. free carbonate and at pH 8.3 requires only 2.8 ppm. Not all of the excess will be deposited, because, as the Ca remaining in solution is reduced, the carbonate required to maintain equilibrium increases. Stability lines indicate that only at pH 8.4 will the loss of Ca equal the difference between the carbonate originally present and the amount required for equilibrium. This amount = 5 ppm., which is the saturation excess of this water.

4. *Assume:* Ca 400, alky. 400, pH 7.85. Find saturation excess or deficiency.
Solution: pH_s = 6.65, S.I. = +1.20. Sample contains 22 ppm. free CO_2. This value will rise as $CaCO_3$ is deposited because the loss of carbonate, only a trace of which is present, will be continuously replenished by dissociation of bicarbonate, in accordance with Eq. (12). Free CO_2 produced equals the carbonate removed by precipitation. Stability lines indicate that only at pH 6.93 will the loss of Ca equal the gain in CO_2 over that originally present. This equals 113 ppm., which is the saturation excess of this water.

5. *Assume:* Ca 30, alky. 20, pH 6.6. Find $Ca(OH)_2$ required to attain stability.
Solution: pH_s = 9.18 and S.I. = −2.58. CO_2 present equals 20 ppm. Addition of lime to form HCO_3 will increase both Ca and alky. by an equal amount. Free CO_2 will decrease to less than 1 ppm. as alky. increases to 30 ppm. This will require the addition of 10 ppm. of lime, and the actual pH will rise to 8.22. The corresponding pH_s, as indicated by the pH_s line, equals 8.82; therefore, the S.I. has been raised from −2.58 to −0.6. Additional lime will be required to raise this index to zero. At pH 8.22, the free carbonate present is less than 1.0 ppm. As more lime is added, the free carbonate present will rise in accordance with the neutralization equation for bicarbonate. This equation shows that two equivalents of carbonate and one of alky. are formed for each equivalent of lime added. Since the final pH must be less than 8.82 and since at this pH only 2.5 ppm. of CO_3 will be required, the point of intersection between the carbonate stability line and the 31 ppm. alky. line should indicate the final equilibrium. The diagram shows that this occurs at pH 8.75 and that the lime required will equal 11 ppm. of equivalent $CaCO_3$, or 8 ppm. hydrated lime. (Compare with experimental data by Moore (9).)

6. *Assume:* Ca 300, Mg 150, alky. 400, pH 7.8. Find theoretical lime requirement for softening and minimum residual Mg and Ca hardness, compatible with the production of a stable water at pH 9.8.
Solution: Diagram shows that at pH 9.8 Mg will be reduced to 90 ppm. This will require 60 ppm. lime (150–90) and will increase Ca to 360 ppm. Diagram shows that at pH 7.8 water contains 24 ppm. free CO_2. Converting this to HCO_3 will require 12 ppm. lime and will increase Ca to 372, alky. to 412 and pH to 8.2. On the principle that in the presence of bicarbonates the further addition of lime will remove itself and lower Ca and alky. one equivalent each, the alky. will remain 40 ppm. (412–372) greater than Ca. The diagram shows that at pH 9.8 this condition is satisfied only if Ca equals 5.0 ppm. and alky. 45 ppm. To accomplish this 367 ppm. of lime, in addition to the 72 already added, will be required. Accordingly, 439 ppm. lime, as equivalent $CaCO_3$ or 325 ppm. hydrated lime, will be required. The residual Mg hardness will equal 90 ppm. and the Ca hardness 5.0 ppm. *Note:* Only in the presence of a perfect catalyzer effective in stabilizing both Ca and Mg could this efficiency be attained in practice.

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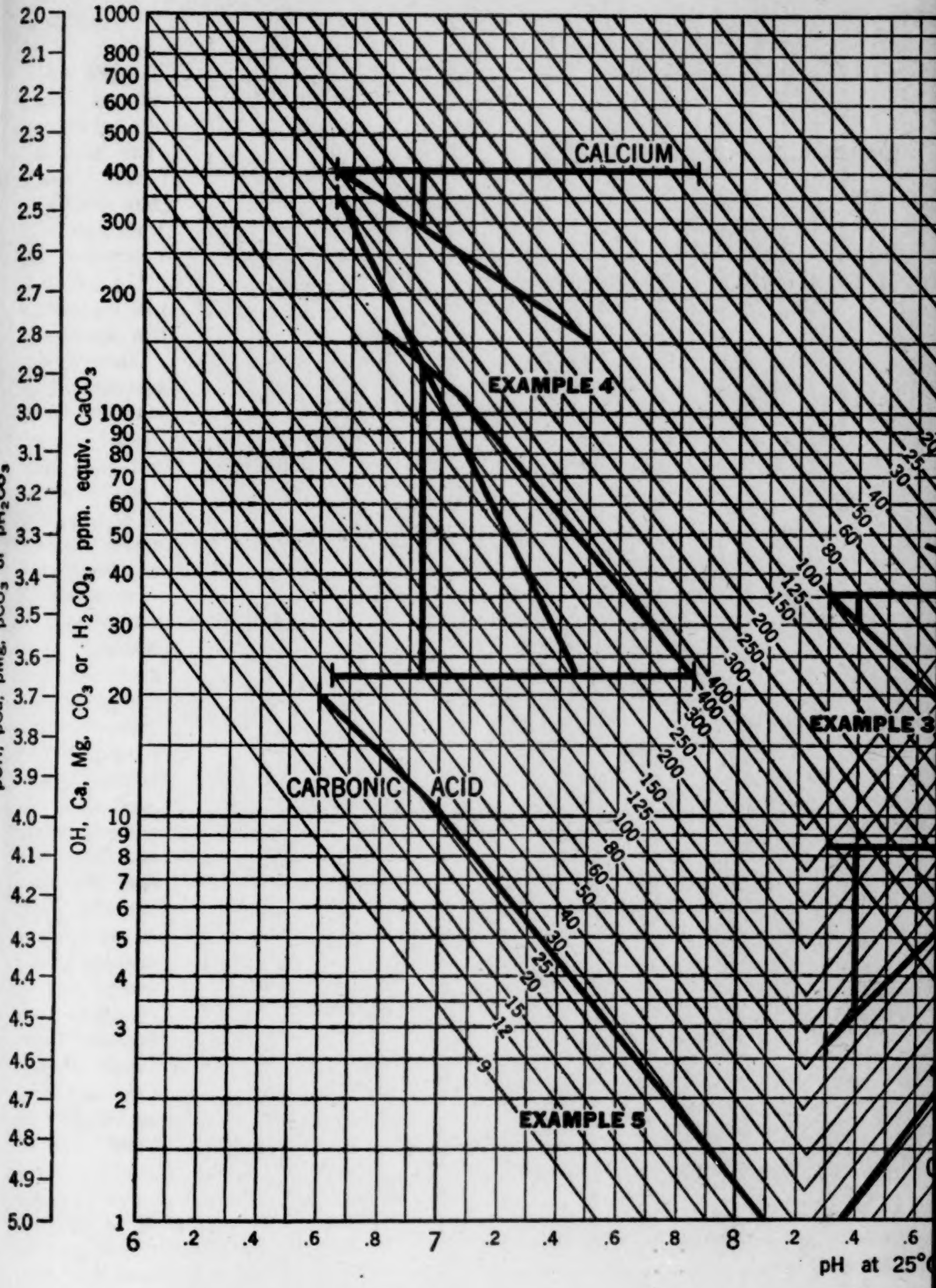
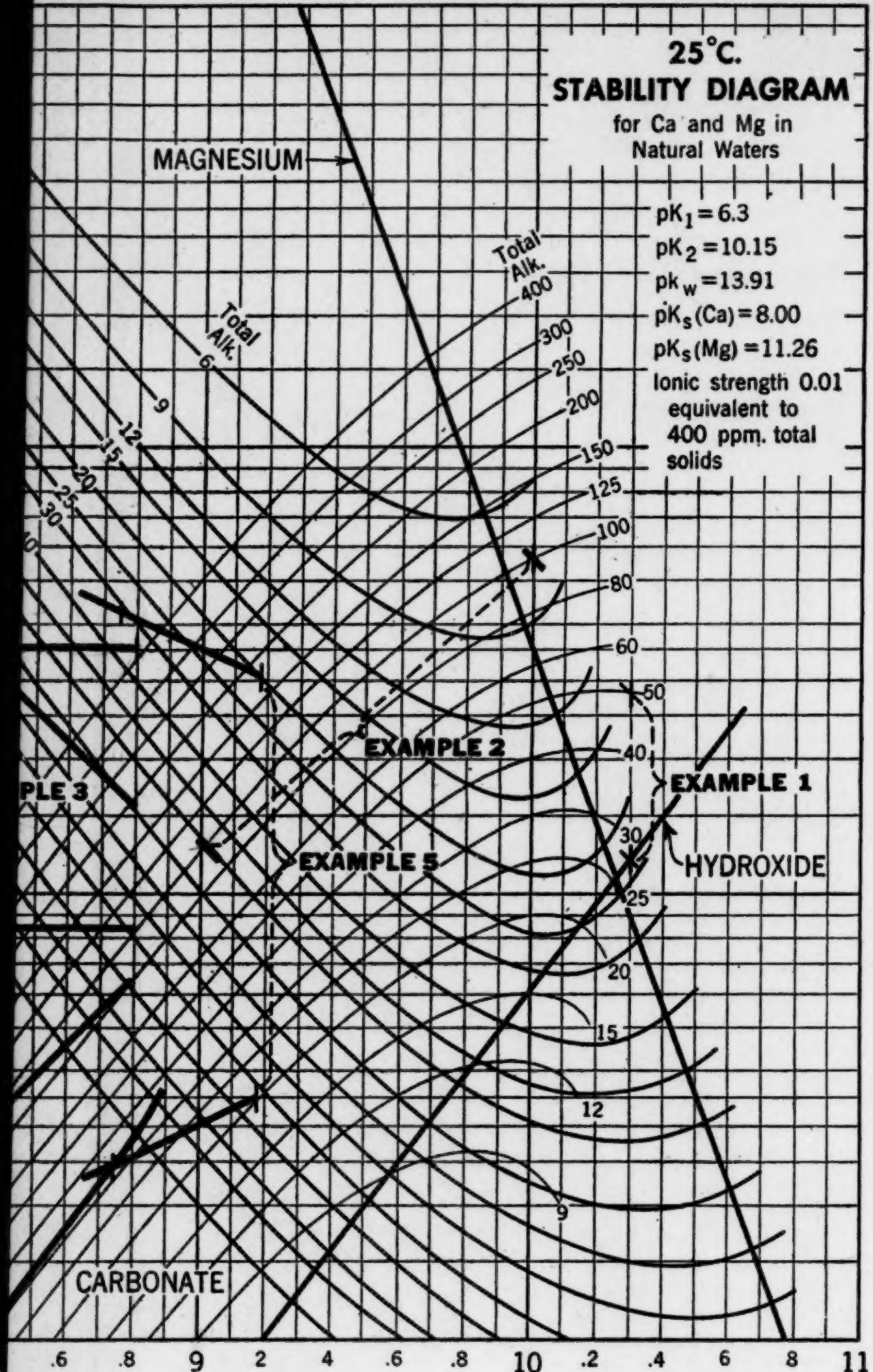


FIGURE 1



25°C.
STABILITY DIAGRAM
for Ca and Mg in
Natural Waters
MAGNESIUM
$pK_1 = 6.3$
$pK_2 = 10.15$
$pk_w = 13.91$
$pK_s(Ca) = 8.00$
$pK_s(Mg) = 11.26$
Ionic strength 0.01
equivalent to
400 ppm. total
solids
Total Alk.
400
300
250
200
150
125
100
80
60
50
40
30
25
20
15
12
9
Total Alk.
6
EXAMPLE 2
EXAMPLE 1
PLE 3
EXAMPLE 5
HYDROXIDE
CARBONATE
.6
.8
9
2
4
.6
.8
10
.2
.4
6
8
11

at 25°C.

GURE 1

In Fig. 1, the lines marked "Calcium" are the equilibrium or solubility values for calcium carbonate given both as pCa and as ppm. of equivalent $CaCO_3$, for corresponding values of alkalinity and pH.

These are the only lines needed for the solution of the hypothetical pH_s, i.e., the pH which the sample would possess if in equilibrium with calcium carbonate without change of its ionic components. To obtain its value it is merely necessary to plot the known calcium concentration on the proper alkalinity line. The corresponding pH read from the bottom scale is the pH_s value. The corresponding value of $pH_{s(Mg)}$ is obtained by plotting the known magnesium concentration on the magnesium line without reference to alkalinity.

The lines marked "Carbonic Acid" and "Carbonate," respectively, indicate the concentrations of each which are in equilibrium with the indicated alkalinity and pH. Their inclusion in the diagram enables the rapid quantitative estimation of the scale-forming or scale-dissolving properties of the water, together with the true or actual pH which the water will possess when complete stability has been obtained. The inclusion of the "Hydroxide" line enables the rapid estimation of all three anion components of total alkalinity.

The several constants which were used in the construction of the diagram are indicated thereon. They vary slightly from the values originally used (1) and are the values recommended by Larson and Buswell (5) corrected for an ionic strength of 0.01 or approximately 400 ppm. of normal dissolved solids. A salinity correction to pH_s should be unnecessary in the case of most fresh waters.

It is believed that the values of the constants used are the most reliable in chemical literature at this time but they are subject to future revision. The value most in doubt is the solubility-product constant of magnesium hydroxide. The pK_s value of 11.26 was determined by Kline (12). A more recent value of 10.513 has been reported by Näsänen (13). The use of the latter value would place the magnesium line in the stability diagram 0.38 unit to the right of its present position. It should also be noted that the values of the solubility product constant for calcium carbonate for temperatures above 25°C. are calculated values and lack adequate experimental confirmation.

It has been suggested that equilibrium calculations are not always dependable because of the formation under certain conditions of complex ions such as $(CaHCO_3)^+$, $(MgHCO_3)^+$ and $(CaOH)^+$. It is well known that, in the presence of added metaphosphate ions, the normal calcium, iron and aluminum equilibria in water are upset in a manner not as yet subject to ready calculation. It is conceivable that complex ions of the type mentioned do occur in significant amounts in normal fresh waters, but the author is inclined to believe that apparent failures in correlating results in practice with theory as presented are more likely due to inaccurate pH measurements, inaccurate constants, especially at high temperatures, or insufficient time allowance for the attainment of stable conditions.

Methods of Using Diagram

In using the diagram to ascertain final equilibrium conditions, it is necessary to distinguish between waters for which pH values fall either above or below 8.2. If both pH_s and pH

TABLE 2

Additional Examples in the Use of 25°C. and 75°C. Stability Diagrams

7\. *Find:* The relative maximum Ca and Mg hardness of water softened at 25° and 75°C. at final pH levels of 9.4, 9.7 and 10.0. Assume stabilization and final alky. of 50.

Solution: The 25°C. diagram indicates respective Ca hardnesses of 7.7, 5.0 and 3.8; Mg hardnesses of 570, 145 and 36 ppm. Fig. 3 indicates that at 75°C. the pH values would equal 8.66, 8.88 and 9.1. Fig. 2 indicates corresponding Ca hardnesses of 6.0, 4.2 and 3.4; Mg hardnesses 40, 14 and 5.2 ppm. Note the marked effect of both temperature and pH on solubility of magnesium.

8\. *Assume:* The conditions stated in Example 3. Find pH_s, S.I. and saturation excess or deficit at 75°C.

Solution: From Fig. 3, the 75°C. pH of the sample equals 8.35. Plotting this value and locating pH_s at 7.5 the S.I. is found to equal +0.85. Draw the stability lines for Ca and carbonic acid as the alky. falls from 100 down to 80. Note that the sample contains 5 ppm. of free carbonate at this temperature, and that the maximum carbonate that can be deposited equals (5–2.7) + (10–2.7) or 9.6. Accordingly, the final pH_s can not rise above that indicated for (35–9.6) or 25 ppm. Ca which is 7.7. Assume a final pH_s of 7.6 and try balancing the loss of Ca against the combined loss of free carbonate and gain in carbonic acid. Loss in Ca = 7. Loss in free carbonate = 2.0 added to gain in carbonic acid 5.0 = 7.0 ppm. Accordingly, the saturation excess at this temperature is 7 ppm. compared to 5 ppm. at the lower temperature, i.e., a gain of 40%. Note that if this water, after attaining stability at 75°C., is cooled to 25°C., its pH will equal 7.7 and its new pH_s will equal 8.45. Its original S.I. of +0.5 has been changed to −0.75. The inference is that in a hot water system a falling temperature, under certain conditions, can affect the corrosion rate adversely. (Compare with ref. (7).)

9\. *Assume:* Conditions as stated in Example 4. Find pH_s, S.I. and saturation excess or deficit at 75°C.

Solution: From Fig. 3, pH will fall from 7.85 to 7.75. From Fig. 2, pH_s = 5.85. S.I. = +1.9, a gain over the 25°C. value of +0.7. At pH_s 5.85 the equilibrium carbonic acid equals 1800 (10 times the value at 6.85), compared to 23 ppm. actually present. Stability lines indicate that at pH 6.47 the loss in Ca and the gain in carbonic acid are equal, i.e. 200 ppm. This compares with 119 at 25°C., a gain of 68%.

10\. *Assume:* Ca 25, alky. 50, pH 10.0. Find S.I., and saturation excess or deficit at 25° and 75°C.

Solution: At 25°, S.I. = 10.0 − 8.78 = +1.22. Final pH_s = 9.55, saturation excess equals 16. At 75°C., pH will fall from 10.0 to 9.1 (Fig. 3), pH_s = 7.97, S.I. = +1.13, a decrease of 0.09. Final pH_s = 8.12, saturation excess = 6.0 ppm. This example illustrates a case (left of S.I. zero change line in Fig. 3) where a rise of temperature decreases the S.I. and also the saturation excess.

11\. *Assume:* Ca 60, alky. 50, pH 9.6. Find S.I. and satn. excess at 25° and 75°C.

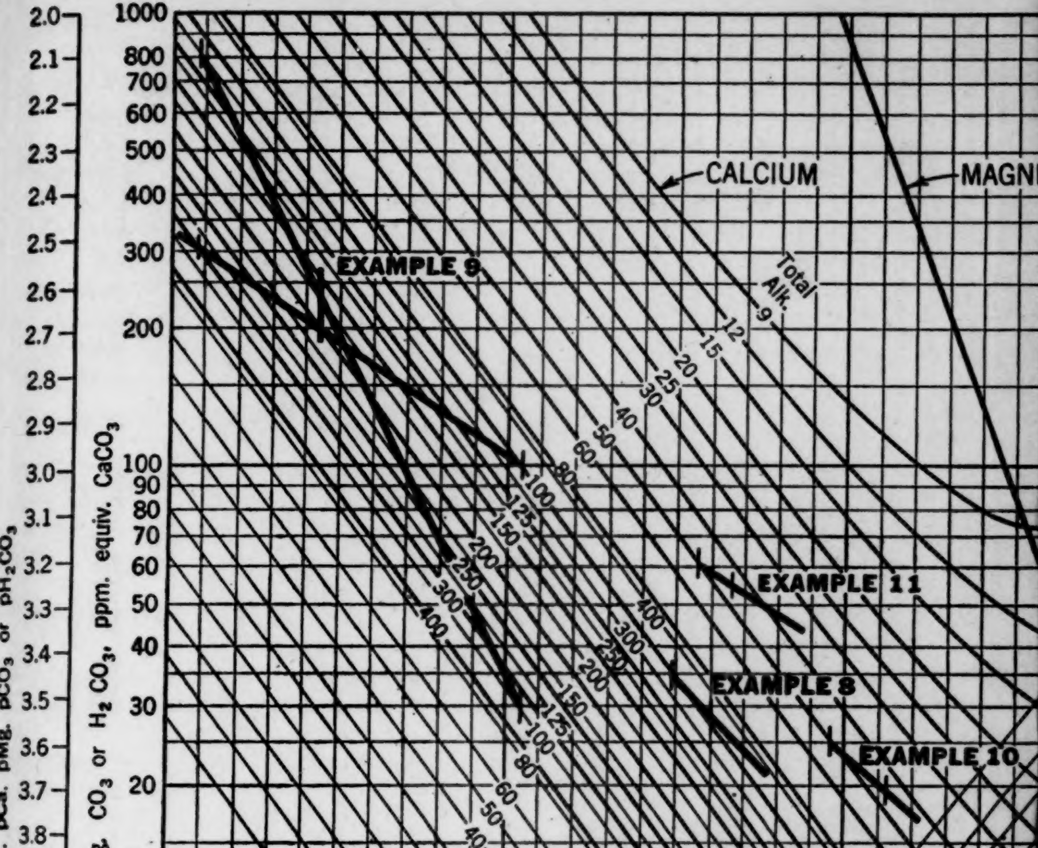
Solution: From Fig. 3 it will be seen that for the stated alky. and pH the S.I. values at the two temperatures should remain constant. At 25°, S.I. = 9.6 − 8.37 = +1.23. Stability lines indicate final equilibrium at pH 8.7 and that saturation excess = 15 ppm. At 75°C. pH will fall to 8.8, pH_s = 7.57 and S.I. = +1.23. Final equilibrium is indicated at pH 7.67 and saturation excess = 6 ppm. Conclusions: the saturation excess has decreased with temperature rise even though the S.I. has remained constant.

12\. *Assume:* Ca 350; Mg 176, alky. 340, pH 7.1. Find residual Ca and Mg hardnesses and lime requirement for selective softening.

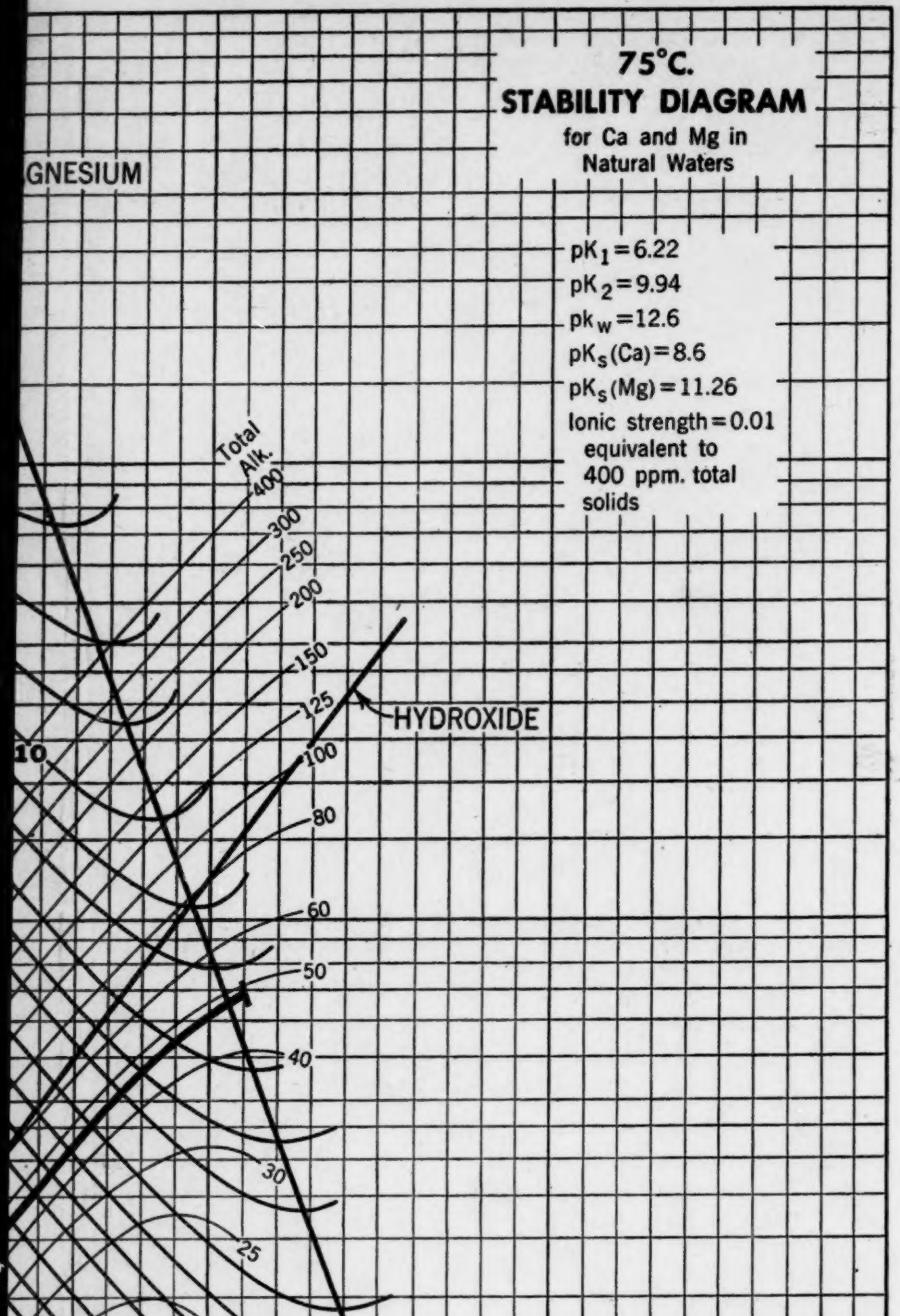
Solution: From Fig. 1, CO_2 = 110. Lime requirement for conversion to HCO_3 = 55. This will increase Ca to 405, alky. to 395, pH to 8.2. Mg will start to precipitate at pH 9.63. Until this pH is reached the residual Ca should exceed the residual alky. by 10. At pH 9.63, Ca = 24 and alky. = 14. Total lime required = 55 + (405 − 24) = 436. This is the theoretical selective softening dosage. (Compare with Test No. 1, Table IV, ref. (10).) Further addition of lime will reduce magnesium but calcium will increase in almost direct proportion.

13\. *Assume:* Alky. 15, de-aerator influent pH 7.0, effluent pH 8.8. Find percentage reduction in total CO_2 and also percentage reduction in combined CO_2.

Solution: From Fig. 1, influent free CO_2 = 6.0, HCO_3 = alky. = 15, total CO_2 = 21. Effluent free CO_2 = 0.1, free CO_3 = 1.2, hydroxide 0.4, HCO_3 = alky. − (hydroxide + carbonate) = 13.4. Removal efficiency based upon total CO_2 = 770/21 = 36.7%, on combined CO_2 = 40/14.6 = 2.66%.


pOH. pCa. pMg. pCO_3 or pH_2CO_3
OH. Ca. Mg. CO_3 or H_2CO_3, ppm. equiv. $CaCO_3$
CALCIUM
MAGNE
Total Alk.
EXAMPLE 9
EXAMPLE 11
EXAMPLE 8
EXAMPLE 10
CARBONIC ACID
CAR
pH at 7

FIGURE



at 75°C.

FIGURE 2

are above 8.2 and the index is positive, the water will contain sufficient free $CO_3^=$ to attain stability without dissociation of HCO_3 ions present. If, however, the pH is less than 8.2, the attainment of final equilibrium involves the dissociation of HCO_3 ions, and the computation of the final equilibrium pH requires consideration of the carbonic acid gained in accordance with the reaction:

$$2HCO_3^- = CO_3^= + H_2CO_3 \quad (12)$$

In this reaction, the equivalent concentrations of $CO_3^=$ and H_2CO_3 formed are equal; therefore, in the process of $CaCO_3$ deposition, if pH is less than 8.2, the $CO_3^=$ deposited from solution is constantly replaced in accordance with the above reaction, and the H_2CO_3 gained during the attainment of equilibrium becomes a measure of the CO_3 ions lost by deposition. Similarly, if the index is negative, the reverse reaction must be considered and the loss in H_2CO_3 becomes a measure of carbonate dissolved.

In general, the first step in the solution of a problem consists in finding pH_s by simply plotting Ca on the proper calcium-alkalinity line. With this point as origin, draw the line which pH_s must follow as stabilization progresses. If the actual pH is greater than pH_s, the saturation index is positive and the path which pH_s must follow will slope downward and to the right, so that the drop in Ca will equal the drop in alkalinity. If the saturation index is negative, the pH_s line will slope upward and to the left, so that the rise in Ca will equal the rise in alkalinity.

The second step involves drawing the corresponding $CO_3^=$ or CO_2 stability line—the former if the pH_s line lies wholly to the right of pH 8.22, and the latter if the pH_s line lies wholly to the left. This line is plotted with pH and alkalinity points corresponding to the pH_s line.

The third step involves the drawing of two horizontal lines, one indicating Ca and the other indicating CO_3 or CO_2 originally present in the sample. The latter is indicated by plotting the pH of the sample on the CO_2 or CO_3 line of proper alkalinity.

The fourth and final step consists of ascertaining by trial the pH at which the change in Ca will equal the change in CO_3 or CO_2. At this pH, the value of the calcium change will equal the saturation excess or deficiency of the sample, and the pH will be the final equilibrium pH. If the actual pH and the pH_s are found to lie on opposite sides of pH 8.22, the problem requires consideration of both CO_2 and $CO_3^=$ changes.

An alternative to the third and fourth steps as described involves the use of a line representing the progressive change in carbonate or carbon dioxide with alkalinity as the water approaches equilibrium. In this case the final equilibrium pH is indicated by the point of intersection with the corresponding stability line.

Use of the 75°C. diagram is the same except that the analytical pH values at 25°C. must be converted to their 75°C. values by the use of a conversion table or diagram (Fig. 3).

Specific examples in the use of the diagrams appear in Tables 1 and 2.

Equilibrium vs. Temperature

It is characteristic of equilibrium equations that they indicate stable end conditions but tell nothing about the rate at which stability is attained. In the attainment of equilibrium, the effect of temperature is of greatest im-

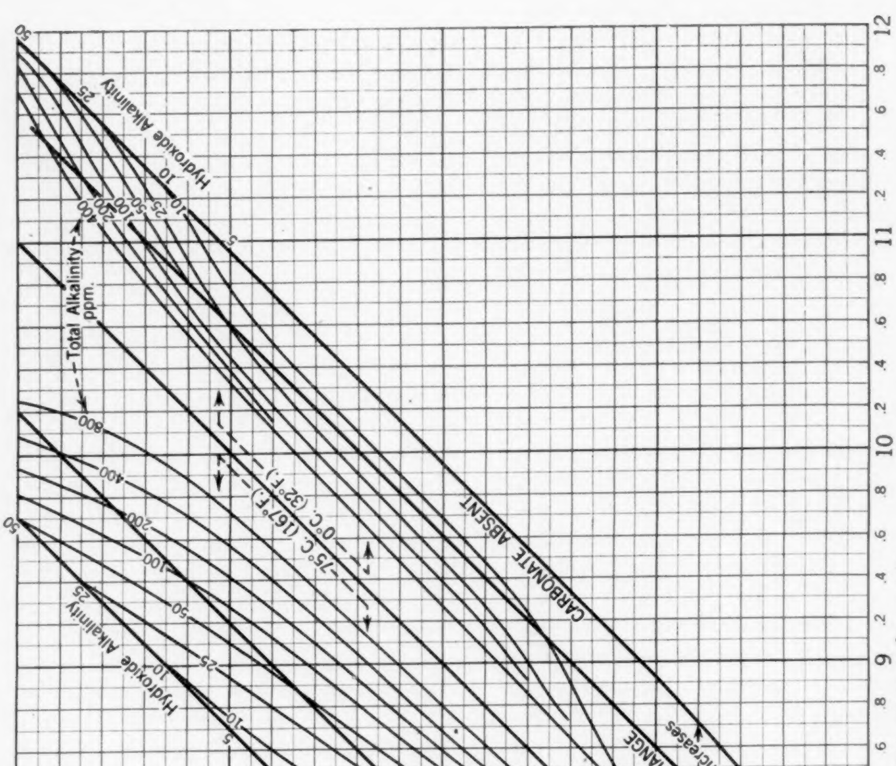

Hydroxide Alkalinity
Total Alkalinity ppm.
CARBONATE ABSENT
S.I. ZERO CHANGE
S.I. Increases
S.I. Decreases
0°C. (32°F.)
75°C. (167°F.)
Measured pH at 25° C.
Actual pH at 75° C. or 0° C.

FIGURE 3

portance. At ordinary temperatures, in the absence of the solid phase or other catalyst, equilibrium is reached very slowly, and days or even weeks may be required to attain complete stability. It is probably true that in cold water distribution systems only a small fraction of a saturation excess is deposited. In hot water systems, the time factor may be reduced to minutes, but it is also probably true that in passing through a hot water system not all of a saturation excess is deposited.

In addition to its effect in shortening the time necessary to attain equilibrium, a temperature rise also results in a displacement of the equilibrium which may operate either to increase or to decrease the saturation excess or deficiency. This is because temperature exerts independent effects upon pH_s and pH, the two values concerned. The former changes directly with the temperature coefficient of $(pK_2 - pK_s)$ and is equal to a decrease of approximately 0.015 unit per degree Centigrade rise in temperature. The temperature coefficient of pH, however, is dependent upon other factors, among them buffer capacity or total carbonate alkalinity. Since at present it is a practical impossibility in routine work to measure the pH of water at the higher temperature levels, resort to computation is necessary. These computations for carbonate solutions of varying alkalinity are quite involved, and reference should be made to the discussion of the subject in the following paper.

The several examples given opposite the 75°C. diagram indicate temperature effects which could hardly have been suspected prior to the working out of the temperature-alkalinity relationships of pH in carbonate solutions. The original simplifying approximation (1), that pH and the saturation equation constant $(pK_2 - pK_s)$ each decrease at the same rate with temperature rise, is now seen to represent average conditions, but it is also apparent that the approximation is entirely inadequate in dealing with waters of varying alkalinity. This is clearly shown in Fig. 3, wherein the actual departures from this assumption, in terms of the net effect upon the saturation index, are indicated. It will be noted that in raising the temperature from 25° to 75°C. the effect of alkalinity is such that it may either decrease or increase the index by as much as 0.5 unit. The examples given in Table 2 show that only by interpreting each index value in terms of actual calcium carbonate excess or deficiency can one ascertain the probable scaling or resulting behavior in hot water systems. Another temperature effect, apparently not hitherto suspected, is the fact that if water which has attained stability in a hot water system is subsequently allowed to cool, the water can change from scale-forming in one part of the system to markedly scale-dissolving in another.

In lime softening satisfactory magnesium removal has been a problem with some waters. This is because the attainment of a sufficiently high pH with the use of lime results in increasing the calcium hardness as the magnesium hardness is decreased. Under these conditions the use of an alkali or recarbonation is indicated. Typical examples in the use of the diagrams reveal clearly the effects of both alkalinity and temperature in this connection.

Summary

This paper explores further the theory of the reversible pipe scaling process and extends the practical ap-

plication of equilibrium equations to problems encountered in the laboratory control of various processes of water conditioning. Diagrams enabling the quantitative interpretation of the saturation index at normal and elevated temperatures are presented.

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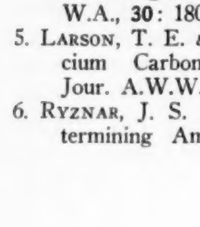

Effect of Temperature on the pH of Natural Waters

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A contribution to the Journal

IN the solution of chemical problems in water technology, particularly as related to water softening and the stability of water in piping systems, it is often advantageous to employ certain well-known equilibrium equations of physical chemistry. In these equations, the several constants, as well as some of the analytical test values, may vary with temperature. For those analytical values which vary with temperature, either the test must be made at the temperature of use or a suitable correction must be applied to the test result. An outstanding example of this is the pH determination. Because most pH testing equipment is standardized for use at or near room temperature, and because measurements made at other temperatures may be very inconvenient or may contain significant errors, the use of the several pH equilibrium equations at either higher or lower temperatures presents a problem, and a method of converting room temperature pH measurements to the actual values at other temperatures should be of considerable practical value. In the case of most natural and conditioned waters, it is possible to do this at least within certain limiting conditions. These limiting conditions require that (1) there shall be no change in total mineral content, i.e., no loss from precipitation or volatilization and no gain from evaporation, (2) the water shall contain salts of carbonic acid but of no other weak acid or base, and (3) the total mineral salts shall not exceed 600 or 800 ppm., so that concentrations can be assumed to equal activities.

The equations involved in calculating $pH_{t°C.}$ values from the 25°C. value are as follows:

$$pH = pK_2 + \log \frac{[CO_3^{=}]}{[HCO_3^{-}]} \quad (1)$$

$$pH = pK_1 + \log \frac{[HCO_3^{-}]}{[H_2CO_3]} \quad (2)$$

$$pH = \tfrac{1}{2}(pK_2 + pK_1) \quad (3)$$

$$pH = pK_w - pOH \quad (4)$$

$$(\text{Alky.}) + [H^+] = 2[CO_3^{=}] + [HCO_3^{-}] + [OH^-] \quad (5)$$

$$[H^+](\text{Alky.}) + [H^+]^2 = K_w \quad (6)$$

$$[H^+] = \frac{-\text{Alky.} + \sqrt{(\text{Alky.})^2 + 4K_w}}{2} \quad (6a)$$

In these equations, the several terms have their usual significance. The brackets imply molal concentration of the ion indicated; pK_1, pK_2, and pK_w represent the negative logarithms of the primary and secondary dissociation constants of carbonic acid and of water, respectively; pH and pOH represent the negative logarithms of the respective molal ion concentrations, and (Alky.) represents the equivalent concentration of titratable base designated in *Standard Methods* as total alkalinity. Equations (1) to (4) inclusive are

equilibrium equations and, as such, each must be satisfied in a given system, except that Eq. (3), which is a special case of (1) or (2), will hold only for the conditions where $[CO_3^{=}]$ and $[HCO_3^-]$ are equal.

Equation (5) differs from the equations of lower number in that it is not derived from application of the law of mass action but rather is based upon the principle of electrical neutrality, one implication of which is that the sum of the cations involved in hydrolysis must be chemically equivalent to the sum of the anions involved.

For the purpose of the present discussion, it is important to stress a basic fact pertaining to Eq. (5), namely, that the individual concentrations of the anion components which, added together, equal toal alkalinity plus $[H^+]$, may vary appreciably with temperature, even though the total alkalinity must remain constant. This fact is the basis of the method which makes possible the calculation of the temperature effect on pH.

Equation (6) is derived by combining a special case of Eq. (5), i.e., where carbonates are absent, with Eq. (4). This equation is not applicable to natural waters, but its inclusion is for the purpose of showing the remarkable buffer capacity of even the lowest concentrations of carbonate alkalinity upon the temperature coefficient of pH. Equation (6a) is the expression of Eq. (6) in the form suitable for the solution of $[H^+]$.

When supplied with known temperature corrected pK values, the above equations can be used to calculate the pH values which correspond to any assigned values of carbonate and bicarbonate. Since, in accordance with Eq. (4), the pH establishes the OH ion concentration at any temperature, and since total alkalinity is equal to the sum of carbonate, bicarbonate and hydroxide, as expressed in Eq. (5), it becomes possible to relate pH with total alkalinity for varying ratios of its component parts at any temperature for which the pK values are known. If the calculations are plotted graphically, it becomes possible to prepare conversion charts from which, given the total alkalinity and the $pH_{25°C.}$ value, the pH_t value at any other temperature can be obtained. A chart of this kind is shown in Fig. 1. Because others may wish to prepare similar charts for different temperature intervals, the procedure used in its preparation will be described in detail.

Method of Preparing Conversion Charts

1. Using Eq. (1), calculate for each temperature the pH_t values corresponding to variable progressive ratios of $[CO_3^{=}]/[HCO_3^-]$ between the limits of $\frac{5}{95}$ and $\frac{95}{5}$. Record the corresponding values of total carbonate alkalinity, i.e., $2[CO_3^{=}] + [HCO_3^-]$ assuming the progressive second step neutralization of 0.25, 0.50, 1.00, 2.00, 4.00 and 8.00 millimolal solutions of carbonic acid. To each value of total carbonate alkalinity add the hydroxide alkalinity as computed by Eq. (4) to obtain the total alkalinities.

2. Repeat similar calculations for the lower range of pH_t values and total alkalinity for each series by the use of Eq. (3).

3. Compute finally the intermediate pH_t values and alkalinity for each series using Eq. (3).

4. From the calculated values, plot separate series of temperature curves for each dilution of carbonic acid represented. In these graphs, plot pH_t values against total alkalinity. It will

be found desirable to plot each series in two overlapping sections, using a wider spacing of the alkalinity coordinate for the intermediate pH range. The pH scale should read to 0.02 unit. Standard rectilinear graph sheets (10 × 15 in.) with 20 divisions to the inch are suitable for the intermediate range, and semi-logarithmic sheets with identical spacing on the long side can be used for the higher range of alkalinities.

5. Prepare from the first set of graphs a second set in which pH_t values are plotted against alkalinity but in which each graph is limited to a constant temperature difference. For this purpose it will be found advantageous to employ either two- or three-cycle semi-log paper. The pH spacing must be the same as in the first set. The individual curves are constructed from points obtained by scaling pH differences at constant alkalinity at 0.2 pH unit intervals throughout the length of the 25°C. curves and plotting these differences at the proper pH and alkalinity levels. In these graphs each curve indicates the progressive change in pH resulting for a constant temperature difference above or below 25°C. for all alkalinities between the lowest and highest represented.

6. The graphs as prepared in Para. 5 can be used in that form or the data taken therefrom can be replotted in the form used in Fig. 1. The data of Table 2 were taken from replotted graphs.

Validity of Data Presented

It is believed that the pH-temperature data of Fig. 1 and Table 2, obtained by the method described, are based on valid considerations and that their accuracy within the limitations mentioned conforms to the accuracy of routine pH determinations and to the accuracy of the several constants employed. The values of the constants used are given in Table 1.

TABLE 1

Values of Constants Used in the Construction of Fig. 1 and Table 2

Temperature °C.	°F.	pK_1	pK_2	pK_w
0	32	6.58	10.63	14.94
25	77	6.36	10.33	14.00
50	122	6.30	10.17	13.26
75	167	6.30	10.12	12.70
100	212	6.34	10.07	12.30

The values of pK_1 and pK_2 for temperatures up to 50°C. have been taken from the most acceptable experimental data which are at present available, and are believed to be accurate. For temperatures above 50°C. the values were obtained by extrapolation and may be slightly less accurate. At pH levels below 7.0, the 50°, 75° and 100°C. curves practically coincide because of the fact that the temperature coefficient of pK_1, which governs in this pH range, has been found to attain a minimum value in the vicinity of 60°C., with only a slight change for a considerable temperature interval in either direction. Considering that most pH measurements of water are at best only accurate to the nearest 0.1 pH unit, the charts were prepared with this degree of accuracy in mind.*

* Since the preparation of Fig. 1 and Table 2, an interesting paper by Powell, Bacon and Lill, "Corrosion Prevention by Controlled Calcium Carbonate Scale," has appeared in the September 1945 issue of *Industrial and Engineering Chemistry*. This paper includes two pH-vs.-temperature graphs in which the pH depression at 100°C. is from 0.2 to 0.4 units greater than in our data. A check of the supporting data indicates that the discrepancies are the result of using higher average values of pK_1 and pK_2 at 25°C. and lower values at 100°C.

Attention should be directed to the fact that commercial colorimetric standards used in pH testing give results which are approximately one-tenth of a unit too low when used in testing natural waters of normal solids content. A salt correction of this amount is indicated unless the waters contain more than approximately 1,000 ppm. total solids.

TABLE 2

For the Conversion of pH Values Measured at 25°C. Into Actual Values at Other Temperatures Applicable to Dilute Carbonate Solutions and Natural Waters Only

	Measured pH 25°C.	Total Alkalinity 10	25	50	100	200	400	800
	≦ 8.0 (Add 0.22 to 25°C. value)							
pH at 0°C. (32°F.)	8.2	8.54	8.50	8.45	8.45	8.45	8.45	8.45
	8.4	8.90	8.72	8.68	8.68	8.67	8.66	8.66
	8.6	9.24	9.00	8.92	8.92	8.90	8.88	8.88
	8.8	9.50	9.28	9.18	9.18	9.18	9.08	9.08
	9.0	9.70	9.50	9.42	9.40	9.30	9.28	9.28
	9.2	9.90	9.70	9.62	9.60	9.52	9.50	9.50
	9.4	10.10	9.90	9.82	9.80	9.72	9.70	9.70
	9.6	10.30	10.10	10.02	10.00	9.92	9.90	9.88
	9.8	10.50	10.32	10.24	10.20	10.14	10.12	10.10
	10.0	10.77	10.60	10.55	10.44	10.36	10.34	10.32
	10.2	11.10	10.90	10.80	10.70	10.63	10.56	10.54
	10.4	11.34	11.26	11.10	11.00	10.88	10.80	10.78
	10.6	11.54	11.54	11.44	11.30	11.16	11.05	11.00
	10.8	11.74	11.74	11.72	11.63	11.50	11.34	11.30
	≦ 7.8 (Subtract 0.08 from 25°C. value)							
pH at 50°C. (122°F.)	8.0	7.85	7.88	7.90	7.90	7.90	7.90	7.90
	8.2	7.95	8.00	8.04	8.06	8.06	8.08	8.10
	8.4	8.06	8.12	8.18	8.22	8.24	8.26	8.28
	8.6	8.20	8.26	8.33	8.40	8.44	8.45	8.46
	8.8	8.34	8.42	8.50	8.56	8.60	8.64	8.66
	9.0	8.48	8.58	8.66	8.73	8.78	8.82	8.84
	9.2	8.65	8.74	8.84	8.90	8.97	9.00	9.04
	9.4	8.82	8.90	9.00	9.08	9.16	9.20	9.23
	9.6	8.98	9.08	9.20	9.28	9.34	9.38	9.42
	9.8	9.14	9.26	9.37	9.45	9.52	9.57	9.62
	10.0	9.32	9.42	9.56	9.63	9.70	9.76	9.82
	10.2	9.48	9.58	9.70	9.80	9.86	9.93	10.00
	10.4	9.66	9.75	9.88	9.94	10.02	10.08	10.18
	10.6	9.90	9.90	10.00	10.08	10.17	10.24	10.34
	10.8	10.08	10.08	10.15	10.22	10.30	10.38	10.48
	11.0	10.26	10.26	10.26	10.34	10.40	10.50	10.60

TABLE 2—*Continued*

	Measured pH 25°C.	Total Alkalinity						
		10	25	50	100	200	400	800
		⋜ 7.6 (Subtract 0.08 from 25°C. value)						
pH at 75°C. (167°F.)	7.8	7.60	7.64	7.66	7.68	7.70	7.70	7.70
	8.0	7.64	7.72	7.80	7.84	7.86	7.88	7.88
	8.2	7.70	7.80	7.90	7.98	8.02	8.04	8.06
	8.4	7.78	7.90	8.00	8.10	8.14	8.20	8.20
	8.6	8.86	8.02	8.12	8.22	8.30	8.36	8.42
	8.8	7.98	8.14	8.24	8.34	8.44	8.52	8.62
	9.0	8.08	8.26	8.38	8.50	8.60	8.70	8.80
	9.2	8.20	8.40	8.52	8.64	8.76	8.86	8.96
	9.4	8.32	8.52	8.66	8.80	8.92	9.04	9.18
	9.6	8.46	8.66	8.80	8.96	9.10	9.22	9.36
	9.8	8.60	8.80	8.96	9.12	9.26	9.40	9.54
	10.0	8.76	8.94	9.10	9.28	9.42	9.56	9.72
	10.2	8.92	9.08	9.24	9.40	9.54	9.70	9.90
	10.4	9.10	9.22	9.36	9.52	9.68	9.82	10.02
	10.6	9.30	9.34	9.48	9.62	9.76	9.92	10.12
	10.8	9.50	9.50	9.60	9.72	9.88	10.02	10.20
	11.0	9.70	9.70	9.70	9.80	9.92	10.08	10.24
		⋜ 7.2 (Subtract 0.08 from 25°C. value)						
pH at 100°C. (212°F.)	7.4	7.20	7.22	7.26	7.30	7.32	7.32	7.32
	7.6	7.26	7.32	7.38	7.42	7.46	7.50	7.52
	7.8	7.30	7.40	7.46	7.54	7.60	7.68	7.72
	8.0	7.34	7.46	7.54	7.64	7.72	7.82	7.90
	8.2	7.36	7.52	7.62	7.72	7.82	7.96	8.06
	8.4	7.42	7.58	7.72	7.84	7.94	8.08	8.20
	8.6	7.48	7.68	7.82	7.96	8.08	8.22	8.36
	8.8	7.56	7.77	7.93	8.06	8.22	8.37	8.52
	9.0	7.66	7.88	8.06	8.20	8.38	8.54	8.70
	9.2	7.78	8.00	8.18	8.34	8.52	8.70	8.86
	9.4	7.92	8.14	8.32	8.50	8.68	8.86	9.05
	9.6	8.06	8.30	8.46	8.66	8.84	9.02	9.22
	9.8	8.20	8.42	8.60	8.80	9.00	9.18	9.38
	10.0	8.36	8.56	8.74	8.94	9.14	9.32	9.54
	10.2	8.52	8.70	8.88	9.08	9.26	9.46	9.66
	10.4	8.70	8.84	9.00	9.20	9.38	9.57	9.76
	10.6	8.90	8.96	9.12	9.30	9.48	9.66	9.86
	10.8	9.10	9.10	9.22	9.38	9.57	9.74	9.92
	11.0	9.30	9.30	9.30	9.43	9.60	9.78	9.94

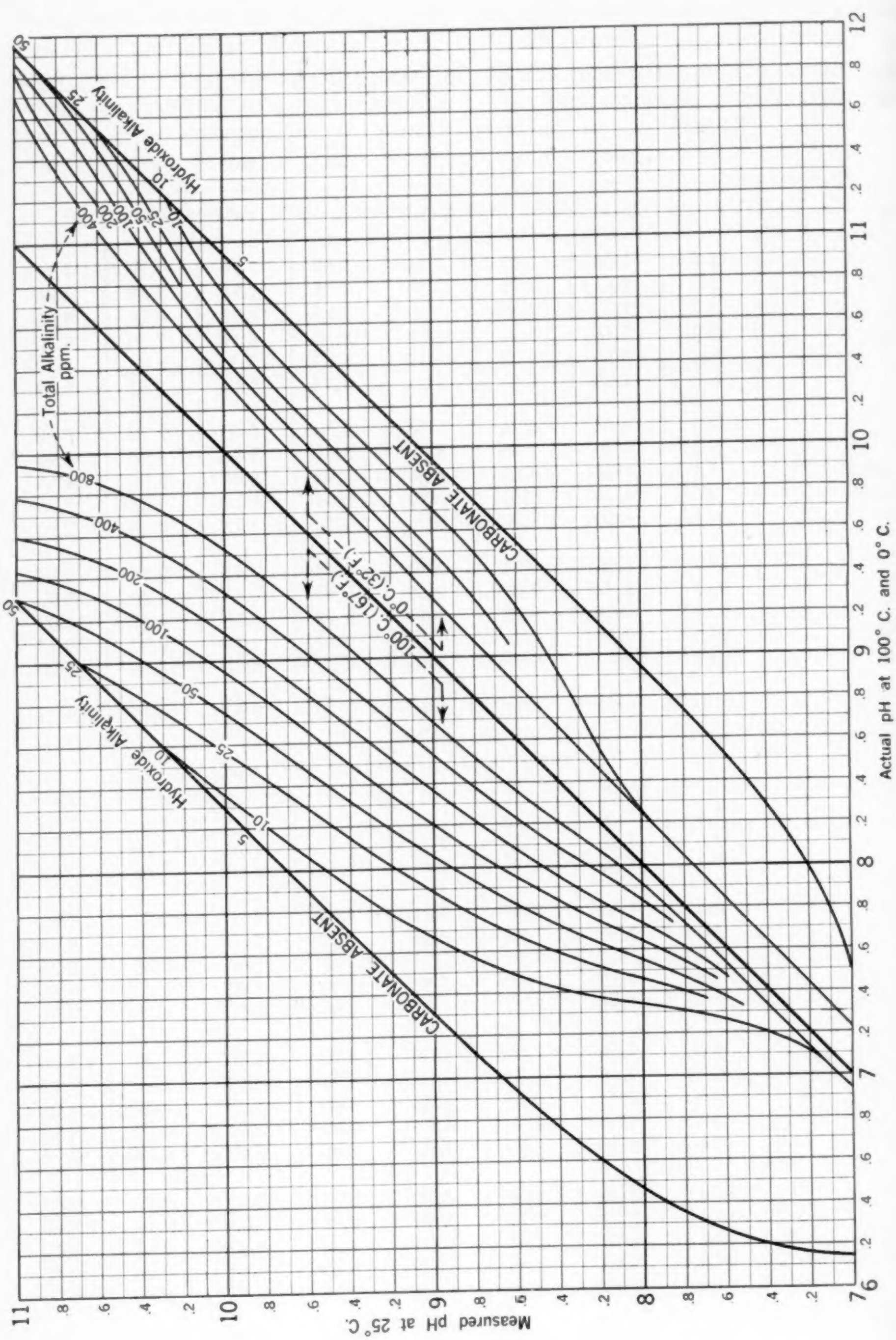
Measured pH at 25° C.
Actual pH at 100° C. and 0° C.
CARBONATE ABSENT
CARBONATE ABSENT
Hydroxide Alkalinity
Hydroxide Alkalinity
Total Alkalinity ppm.
0° C. (32° F.)

FIGURE 1

Buffer Capacity

An interesting observation resulting from an examination of the chart presented is the pronounced buffer effect of even the lowest concentrations of carbonate and bicarbonate ions in reducing the temperature coefficient of pH. This is apparent in Fig. 1, wherein the two outer or enveloping curves calculated by the use of Eq. 6a show the greater effect of temperature on the pH values of neutral water and dilute hydroxide solutions containing no carbonate or other weak acid salts.

Summary and Conclusions

This paper describes the construction of a diagram for the conversion of room temperature pH measurements of dilute carbonate solutions into values at other temperatues between 0° and 100°C. Within specified limitations the data are applicable to natural waters. The effect of total alkalinity or buffer capacity is noted. The data are intended for use in water softening and water pipe incrustation calculations which are discussed in the preceding paper.

Acknowledgment

In concluding these two papers the author wishes to acknowledge much valuable assistance from D. H. Caldwell, Sanitary Engineer, Public Works Department, 12th Naval District, San Francisco, Calif.

Chemical Weed Control

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THE use of chemicals for the economical control of weeds in and around reservoirs is rapidly becoming important because it eliminates sources of tastes and odors in water and results in less annoyance and grievance to consumers. It is a subject on which there has been too little study and research and about which there is much misunderstanding. Moreover, there has not been a clear evaluation of important and pertinent factors applying to the water works practice. It appears to be nature's intent eventually to make land from every body of shallow water, and in this transformation water weeds play an important role. Aquatic weeds appear to be gaining headway in all parts of the country.

Considerable progress has been made in the past 50 years in the development of chemicals and methods of application for controlling land weeds. Little of this experience has been used by the water works profession, yet it is the best answer to the control of shore line growths and all types of vegetation rooted in water but growing largely above the water surface, referred to hereinafter as "emergent growths." Progress in controlling strictly aquatic growths by chemical means has been confined to the past ten-year period and has been largely restricted to controlling weeds in irrigation canals, ditches and reservoirs. The use of such chemicals in domestic reservoirs has been limited because: first, the fear of consumers' complaints of chemical tastes following periods of treatment; and, second, reports that in some cases fish casualties have been high. Recently there has been a move to render such chemicals less odor producing.

Rather than draw a hard and fast line between land weeds and strictly aquatic weeds, an effort will be made in this paper to co-ordinate these once-considered separate fields, because the chemicals now used for both purposes are quite similar, the effects on plant growths in general are identical and the technical problems of control are the same. Some compounds used are poisonous and others must be handled with special precautions, but all should be studied carefully to determine their possible effects on water quality; and, even in the case of land weed control, the effect, if any, on underground water quality must no longer be overlooked. The water works operator must be aware of weed control practices by private and governmental operatives on the watersheds in order to safeguard the water quality of both surface and subsurface water supplies.

The older processes of oiling, burning, raking, dragging and chaining still have their special applications. For instance, when a reservoir can be lowered, the exposed weeds can be sprayed

with a heavy fuel or diesel oil and allowed to dry for about ten to fourteen days. Then, a light oil can be sprayed on it and everything burned. Vegetation along ditches can be seared with burning heavy oil, allowed to die and later be burned completely by a flame thrower. Generally, such methods are only temporary expedients and are time consuming and costly. The use of chemical methods is far more scientific and satisfactory. During the war, chemical weed control received an impetus because of the shortage of labor and the scarcity of oil. Yet, chemical control of weeds is neither simple nor easy. It cannot be considered child's play. Under no circumstances should novices experiment. Already there has been too much unnecessary killing of cattle, destruction of fish, creation of tastes and neglect in evaluating the most important factors involved which threaten further development. For these reasons conflicting reports are being circulated, prejudices are being established and it is becoming increasingly difficult to obtain the truth.

Land Weed Control

Land weeds are of great concern to agriculturists, and enormous quantities of herbicides are used annually. The federal government, through its U.S. Department of Agriculture and Soil Conservation Service, is vigorously promoting programs to suppress undesirable growths on range lands, pastures and drainage ditches. In Texas, major emphasis is on the eradication of Mesquite and Juniper, which, in California, are valuable desert shrubs. The Civil Works Division of the War Department has used herbicides to control salt cedar (*Tamarix gallica*) in canals and river channels of the Southwest. State departments of agriculture throughout the country are fully informed on chemical weed control measures and are openly recommending expanding use. The U.S. Forest Service uses herbicides on fire breaks and in the suppression of irritant shrubs. Chemicals are used in the control of weeds along railroads, utility rights-of-way, at airports, tennis courts and parking lots. The use of herbicides is steadily increasing.

The use of chemicals for land weeds can be divided into three categories: (1) where it is the intent to sterilize the soil temporarily to permit no growth whatever; (2) where all plants treated are killed but the soil remains suitable for crop production; and (3) where chemicals are added to kill specific growths, even though the chemicals are simultaneously applied to other growths. The water works man is interested in all three types of control. Certain areas, such as dirt roads, tops of earth dams and the zone between high and low water level of reservoirs, should be made sterile and be kept barren. Whereas, in the care of the downstream slopes of hydraulic fill dams, the banks of earth canals, the vicinity of reservoirs and around utility yards, vegetation of the right type should be encouraged and pest weeds only should be controlled. Dandelions in lawns, poison oak or poison ivy near roads can be controlled by selective action of specific herbicides.

So wide is the field of herbicides for land weeds that no effort will be made in this paper to list or identify weeds which have been controlled, or to give complete information on the types of chemicals used. One of the best references for chemicals used in land weed control is given by Robert A. Stetson in an article on chemical weed killers (1), which includes a bibliography of

36 other articles. Other practical references include "Weed Control" (2) and "Weeds of California" (3). Full directions are supplied by manufacturers for mixing and spraying and general instructions as to rates of application per acre are furnished. These instructions are apt to be most misleading. Here is where experience comes in and where carefully kept records and photographs of work before and after treatment are valuable. Also, the reader is advised, in general, to treat during the growing season, but experience gained the hard way only will lead to final successful practice.

Some of the basic chemicals used for land weed control, covering a very wide variety of trade names not mentioned in this report, include:

1. *Inorganic Chemicals*

a. *Arsenicals.* Arsenicals sterilize soil, kill plant roots, are toxic to animals and man and are the most widely used herbicides to date. Sodium arsenite is the basic ingredient and compounds usually average 5 per cent arsenic. Water works men have refrained from using arsenicals, but they have been unduly cautious. So long as the arsenic content in the delivered water does not exceed 0.05 ppm., there need be no concern in the use of these compounds where they can be used to advantage.

b. *Salt.* Plain salt (sodium chloride) applied 1 lb. per gal. per sq.yd. sterilizes soil temporarily, that is, until it is washed out by rain.

c. *Sodium chlorate.* This has been used in a great variety of formulas. Used alone in 2–4 per cent concentrations by weight, or 4–8 oz. per gal. on 10 sq.yd., it is very effective on a great variety of weeds, and is toxic neither to animal nor man. However, it is highly dangerous from a fire standpoint. As soon as the water evaporates, it ignites readily. Even clothes splashed with the chemical when dried will start to burn. Obviously, the addition in various amounts of such substances as calcium chloride, borax, vanadium pentoxide and manganese salts has been largely to offset and prevent firing. Dyes have been added so the operator can see where the chemical may have splashed on burnable materials. Where destroyed weeds are later to be raked up and burned, the fire repellents will defeat easy burning, unless rains in the meantime have washed the chemical from the weeds.

d. *Sulfates.* Sulfuric acid is useful in killing trees by the "ring" method. Copper sulfate in a 10 per cent solution, with 1 gal. treating 250 sq.ft., is good in soil sterilization work. Ferric sulfate and ammonium sulfate in the ratio of 3 to 2, applied at a rate of 7 oz. to 1 sq.yd., is specific for pearlwort.

e. *Carbon bisulfide.* This has been used largely on bindweed. It is explosive, inflammable and dangerous to store or transport.

f. *Borax.* Borax is the chief ingredient of Nox-Weed, one of the newer formulas for solutions containing it, and is particularly effective against willow trees. It adds measurable amounts of boron to the water supply and must be used with caution where the water is used to irrigate citrus and tropical trees. Impure deposits of borax are used by direct scattering on soil.

2. *Petroleum Fractions*

Kerosene, gasoline, coal oil and diesel oil have been used as herbicides and still have important roles. The oiling of reservoir banks every three years is good practice, provided the banks are steep and no attempt is made

to lay down excessively heavy blankets of oil in shallow coves. Weeds which have been killed by oil obviously can be easily burned before they are thoroughly dried out. Oil, in general, does not translocate too far into root systems. It does, however, kill buds beneath the bark. Willow trees up to 1-in. trunk diameter can be killed with oil which, applied to the leaves, is carried to the roots; however, plants which reproduce by sending up new shoots are not controlled.

3. *Organic Chemicals* (*other than petroleum fractions*)

a. *Thiocyanates.* These are less active than chlorates but are safer. A dose of 2 lb. per square rod kills most weeds. Ragwort is destroyed by a 2.5 per cent solution 200 gal. of which are applied to an acre.

b. *Furfural.* This is usually a kerosene (45 parts), xylol (45 parts) and furfural (10 parts) mixture applied at the rate of 500 gal. per acre, and is satisfactory for dandelions and deep-rooted perennials.

c. *Ammonium sulfamate.* This is non-toxic, is not a fire hazard and is specific for poison ivy and poison oak, but breaks down to a fertilizer. This is of an advantage to agriculturists but a disadvantage to the water works man because it aggravates algal growths. Sulfamic acid, though a little harder on equipment, has been found equally satisfactory in parallel test runs and does not break down to a fertilizer.

d. *Dinitro-ortho-cresol and its derivatives.* This is one of the new compounds.

e. *Dichlorphenoxacetic acid or its salts* (4). These substances in very low concentrations were, previous to 1945, considered growth-regulating (hormone) substances, but it has been discovered that in stronger amounts plants literally grow themselves to death. These compounds are formed by the reaction of dichlorphenol (a chlorinated phenol) and acetic acid. The chlorine is combined with the second and fourth carbon atoms of the phenol molecule and the compound for short is called 2,4-D. It is insoluble in water and liquid preparations (9.6 per cent 2,4-D) are usually made with an emulsifier, such as carbowax, for dilution to a 0.1 or 0.2 per cent solution for spraying. The salts in powdered form dissolve in water and wetting agents are added to secure uniform coverage of plants sprayed. Manufacturers recommend a dosage rate of 200 gal. (1 per cent 2,4-D) per acre for most weeds, with consideration given to the type and amount of the growth. Actual practice indicates better results with 0.5 per cent instead of the basic 1 per cent rate. The effect of 2,4-D on plants is weird and unnatural. The stems and leaves twist and bend and the root system overgrows itself. Four to eight weeks may be required for the weeds to die. Except for grass, 2,4-D kills everything, even the morning glory with its deep roots sometimes reaching depths of 20 ft., which heretofore have been most difficult to destroy. The 2,4-D compounds have successfully killed: artichoke thistle, bentgrass, blue lettuce, bull thistle, canadian thistle, chickweed, chicory, clover, cockle burs, dandelion, fennel, gaura, jap honey-suckle, klamath weed, knotweed, mallow, milk thistle, morning glory, mustard, pigweeds, plantain, poison oak, puncture vine, purslane, ragweed, russian knapweed, sow thistle, sumac, water grass, white top cress, wild blackberry, wild oats, wild radish and yellow star thistle.

In some instances particular care in the use of wetting agents and thoroughness in spraying are required. This is the most promising chemical for "emergent growth" control. Whether the compounds sterilize soil, which is a controversy among agriculturists, is of no concern to the water works profession. In fact, there are cases where sterility of the soil would be advantageous. It should be realized that there is much to be learned about the use of 2,4-D. Its effect on lateral roots at different stages of the plant's life cycle remains unknown. Several sprayings are needed for most types of plants to obtain a 100 per cent kill.

Commercial brands of 2,4-D include En-Dow-Weed, Dow A-510, Weed-Tox, Weedone, Phenox Weed Killer, Slayz-Weed, Slayz-Weed 60, Weedicide, and Dee-Cee-Pee, as furnished by six competing companies.

f. *Dinitro-ortho-secondary butyl phenol.* This chemical was developed to replace oil during the war, and is said to have better action on certain weeds. The author has seen a test plot of wild parsnip fairly well eliminated with a spray of 6 per cent of the chemical in 85 per cent oil along the McNally Canal in Owens Valley, treated July 26, 1945.

The author has had experience with all the types of chemicals above mentioned, and recommends that careful consideration be given to the selection of the chemical best suited for each particular job. Different chemicals have their advantages and these should be capitalized. If ground is to be sterilized, certain chemicals are best. If destruction by translocation (absorption by the leaves and carrying of the chemicals to the roots) is required, the 2,4-D compounds are, undoubtedly, superior. In some cases, 2,4-D compounds could be used on broadleaf weeds and mixtures of various other chemical sprays could be used for devil grass on the same areas. Likewise, some chemicals have specific disadvantages. If animals and fish are to be protected, toxicity must be considered. Proper selection must be made from a wide variety of spreading or wetting agents to secure coverage of spray on foliage. Experience and judgment remain paramount.

So far as the experience of the Department of Water and Power of Los Angeles is concerned, good results have been obtained with Nox-Weed on willow shrubs; with 2,4-D mixtures on wild parsnip and general weeds; and with ammonium sulfamate on poison oak.

There is much to be learned when it comes to applying chemicals. Ordinarily, plants should be sprayed when young and vigorous, with equipment having sufficient pressure to give thorough atomization, and at the same time strike the vegetation with considerable force. It is recommended that spraying with sulfamate be preceded with a water fog spray. In most other instances, the spray should be applied just after the morning moisture has evaporated from the leaves in order to prevent dilution and sliding off of the chemical. If plants are sprayed too early, or with too strong a concentration, the tops may appear to be quickly killed back, but sprouts may appear later. If sprayed too late in the season, results may be erratic and seeds may not be killed. Certain manufacturers specify that 70°F. is about the best treating temperature. Probably the best criterion to insure good results is to treat when the plant is in its prime and is actually growing.

Mixtures of 2,4-D dry powder with various oils and different weed chemicals can be used to advantage on trees, large shrubs and in special problems. One operator used diesel oil fortified with 2,4-D powder in the ratio of 1 lb. of powder to 100 gal. of oil. Since the 2,4-D powder dissolves in but a few oils, a combination of 1 to 2 lb. of powder to 96 gal. of water and 4 gal. of oil has been suggested. In this case, mechanical agitation must be provided. Trees are best killed by cutting them close to the ground, frilling them with a ring at ground level, and pooling with fortified oil, as described above, or with 10 per cent chlorate or 5 per cent arsenite.

Great care must be taken to protect perennials near where weeds are being sprayed with 2,4-D compounds. Orange and lemon trees have already been inadvertently killed. In one instance, an irrigation ditch drained of water was sprayed with 2,4-D compounds and no trouble resulted when water was subsequently run through it onto garden crops, but when water from the same ditch was later spread onto a cotton patch the cotton plants were affected.

Careful consideration must be given to the effect of 2,4-D compounds on creating odors in water supplies, as some of the 2,4-D compounds contain 45 per cent dichlorphenol. Until further investigations have been made all vegetation sprayed by 2,4-D compounds should be cut, raked and burned, preferably before it can be rained upon, to destroy any remaining chemical. One 2,4-D manufacturer in starting up a new location spoiled several batches, which resulted in the discharge of some dichlorphenol into a sewer system leading to an activated sludge plant, which in turn discharged into a practically dry river channel. This effluent which seeped into the ground in the vicinity of wells spoiled the water supply for more than 6,000 consumers. The resultant dilution was less than one to ten million. The question immediately arises concerning the purity of the 2,4-D compounds as offered on the market. They certainly should be free of appreciable amounts of dichlorphenol. Commercial 2,4-D compounds diluted to one to ten million have a noticeable odor, and the threshold dilution is about one to one hundred million. It is thus apparent that care must be taken so far as the wholesale use of such compounds by the public on watershed areas is concerned.

Emergent Weeds

Emergent weeds retard flows in streams, aqueducts and canals, and provide harbors for troublesome protozoal and algal growths. Generally, they have been reported as clogging ditches, plugging drains, fouling lakes, endangering swimming, interfering with fishing and causing excessive transpiration losses. That they cause serious tastes in water supply by their own disintegration, and from secondary algal growths which they support, is a fact which cannot be lightly set aside. Growths should be controlled early before they literally take over their environment.

Emergent weeds are rooted in mud. They grow in water and support leaves and flowers 1 ft. or more above the water surface. The most troublesome types, and by no means a complete list, are identified according to Jepson (5), as shown in Table 1.

Until recently, it has been difficult to cope chemically with emergent weeds. Cattails and tules, and their roots, were

successfully killed on Nov. 24, 1943, at Upper San Fernando Reservoir by spraying with Nox-Weed, yet tules similarly sprayed at Bouquet Reservoir in November 1944, were killed but new tules appeared from underground shoots immediately adjacent to parent plants. Rushes were killed in July 1945 at Girard Reservoir by use of the same chemical. The new 2,4-D compounds have been tried on all types of emergent growths, but it will not be till next year that definite proof that roots have been killed will be available. Johnson grass, the bane of all irrigators, is efficiently killed by 2,4-D compounds.

Sedges and rushes have been killed by cutting plants below the water line and treating with many types of chemicals, such as cloroben, copper sulfate and arsenicals, but this method now appears antiquated.

It is the general consensus of those who were questioned by the author that in treating emergent weeds the use

TABLE 1

Common Name	*Botanical Name*
1. Arrowhead Family—Duck Potato	*Sagittaria*
Tule Potato	*S. latifolia*
2. Bur-Reed Family	*Sparganiaceae*
Bur-Reed	*S. eurycarpum*
3. Cattail family	*Typha*
Common Cattail	*T. latifolia*
4. Evening Primrose Family	*Onagraceae*
	Jussiaea
Yellow Water Weed	*J. Californica Jepson*
5. Grass Family	*Gramineae*
Ditch Grass	*Paspalum*
Ditch Grass	*P. larranagai*
Joint Grass	*P. distichum*
6. Pickerel Family—Mud Plantain	*Pontederiaceae*
	Heteranthera
Water Hyacinth	*Eichornia crassipes*
Water Stargrass (also submerged)	*H. dubia*
7. Rush Family	*Juncaceae*
Common Rush	*J. patens*
8. Sedge Family	*Cyperaceae*
Water Sedge	*C. aquatilis*
Club-Rush and Bulrush (many species)	*Scirpus*
Common Tule	*S. acutus*
9. Water Plantain	*Alismaceae*
Water Plantain	*Alisma*
	A. plantago
	Damasonium
	Echinodorus
	E. cordifolius
10. Water Milfoil Family	*Halorageae*
Mare's Tail	*Hippurs vulgaris*

of 2,4-D compounds excels all, and that emergent growths should be treated as if they were land weeds. With ordinary care, all emergent weeds can be easily and readily controlled. Cases of failure have been largely due to neglect to follow up with subsequent treatments and to expecting too much from a single treatment.

Aquatic Weeds

Aquatic weeds include algae, mosses and plants. Since algae and mosses, particularly angel's hair or horsetail moss, can be readily controlled by use of copper sulfate or Benoclor, they are not classified in this paper. They must be controlled because they create major problems in clogging ditches and canals, in restricting carrying capacity of canals and aqueducts, in clogging screens at intakes and in creating odors and tastes in domestic water supplies.

Aquatic weeds, other than emergent growths, divide themselves naturally into three groups: (1) plants leaning on the water for support by use of pads and flowers; (2) plants entirely submerged except for blossoms which may need to mature in the air; and (3) free-floating plants without roots permanently located in mud. Principal offenders, according to Jepson's system of classification, are shown in Table 2.

It is to be noted that water weeds cover a wide range of complexity so far as structural features are concerned. Some, like *Chara,* a stonewort, are intermediate between typical algae which they structurally resemble and the higher plants, the general form of which they simulate. They remove calcium carbonate from the water and produce a limy formation on the leaves and stems which makes them quite rough to touch. Their reproduction is simple and is effected by a pear-shaped ovary containing one egg adjacent to a male organ which resembles a brightly colored microscopic orange, both of which can be seen with the aid of a hand lens at the base of the branches. This organism is easily destroyed. On the other hand, some of the weeds, like the *Potamogetons,* are very highly specialized and, in fact, are trees rooting in as much as 35 ft. of water. They remain submerged except for the flowers which, in most varieties, must reach the air and depend upon flying insects for fertilization. Some *Potamogetons* may propagate by as many as five different methods; bud, seeds, joints, tubers and roots. Some weeds, on the other hand, flower and fruit entirely below the water surface. These complications must be considered in the ultimate eradication of water weeds. It is therefore important for one using chemicals for weed control to be able to identify the more common species, to know their reproducing and growing characteristics and their habits of growth. In this connection, the chemical constituents of the water, the type of mud in which the plants take root, the temperature of the water and the amount of water motion probably bear more on the problem of successful chemical control of weeds than has been recognized so far.

Chemicals Used in Aquatic Weed Control

Four types of chemicals have been used for aquatic weed control; namely, sodium arsenite, copper sulfate, chlorine and Benoclor.

Arsenicals

Commercial meta-arsenite ($NaAsO_2$), containing 4 lb. of arsenic oxide (As_2O_3) per gallon, is being used

TABLE 2

1. *Plants leaning on the water with pads and blossoms:*	
a. Water-Lily Family	*Nymphaeaceae*
Pond Lily	*Nymphaea*
Water Shield	*Brasenia*
2. *Plants entirely submerged except for blossoms which may or may not mature in the air above the water level:*	
a. Frog's Bit Family	*Hydrocharitaceae*
Water Weed or Anacharis	*Elodea canadensis*
b. Stonewort Family (Muskgrass)	*Chara*
c. Mustard Family	*Cruciferae*
(Above water in summer)	*Radicula*
Watercress	*R. nasturtium-aquaticum*
d. Pondweed Family	*Naiadaceae*
(1) *Pondweeds*	*Potamogeton*
Thick Leaf Pondweed	*P. lucens*
Leafy Pondweed	*P. foliosus*
Slender Pondweed	*P. pusillus*
Sago	*P. compressus*
Eel-grass Pondweed	*P. pectinatus*
(2) *Pondweeds* (Wigeon Grass)	*Ruppia*
Ditch Grass	*R. maritima*
(3) *Pondweeds*	*Zannichellia*
(Flower and fruit under water)	
Horned Pondweed	*Z. palustris*
e. Water-Milfoil Family	*Halorageae*
(1) Western Milfoil	*Myriophyllum hippurioides*
(2) American Milfoil	*M. spicatum*
3. *Surface and free-floating plants:*	
a. Bladderwort Family	*Utricularia*
Common Bladderwort	*U. vulgaris*
b. Duckweed Family	*Lemnaceae*
Duckweed (Star Duckweed)	*Lemna*
Gibbrous Duckweed	*L. gibba*
Smaller Duckweed	*L. minor*
c. Hornwort Family	*Ceratophyllaceae*
Hornwort-Coontail	*C. demersum*
d. Parsley Family	*Umbelliferae*
	Hydrocotyle
Water Pennywort	*H. ranunculoides*
e. Purslane Family	*Portulacaceae*
(Rooted in shallow water)	
Indian Lettuce	*Montia*
Water Chickweed	*M. fontana*

widely in fish ponds, private ponds and lakes. Obviously, arsenicals are poisonous to man and animals, and their use must be restricted to places where the concentrations of arsenics reaching consumers shall be accurately controlled so as not to exceed 0.05 ppm. Arsenicals are sprayed onto the surface of the water to give a dose of about 1.0 to 2.0 ppm. of arsenic, with two to three follow-up treatments required. The following growths have been successfully treated with arsenic: *Ceratolphyllum demersum, Potamogeton interior, Elodea canadensis, Heteranthera dubia.* Fish and fish food are not affected by dosages usually employed (6). At Toluca Lake, after repeated treatments with arsenicals, it appeared that pond lilies, which were killed at first, developed resistance to subsequent treatments.

Copper Sulfate

Copper sulfate has been used widely to control aquatic growth, although little is understood about its use. One outstanding accomplishment was the almost complete annihilation of *Potamogeton pectinatus* in Ivanhoe Reservoir (capacity, 34 mil.gal.; area, 9 acres) of the Los Angeles water system by the addition of 4,000 lb. of copper sulfate on May 16, 1945. Tons of "hay" were removed when the growth sloughed off near the roots and were blown ashore. The copper sulfate had been uniformly distributed in pea-sized crystals over the flat bottom of the reservoir. Yet, when a similar treatment for the same type of growth was given to Pressure Break Reservoir (capacity, 34 mil.gal.; area, 7.3 acres) in August 1945, results were negative. It was later in the season, the reservoir bottom was not flat and the previous continual feeding of small concentrations of copper may have built up a copper tolerance in the plants. *Potamogeton* was successfully killed at Upper San Fernando Reservoir (capacity, 660 mil.gal; area, 83 acres) on Aug. 7, 1944, when the aqueduct at Dry Canyon Reservoir was treated with 7.038 lb. of copper sulfate primarily to control slime growths in the aqueduct. The kill was most astounding. Copper sulfate sprinkled dry over reservoir bottoms before refilling kills roots and seeds of *Potamogeton.* This was proved at Silver Lake Reservoir where all water weeds were successfully controlled for seven years. After the last cleaning, no treatment was administered and growths are now appearing. There is much to be learned so far as the use of copper sulfate is concerned.

Chlorine

Two experiments were made in July 1924, one at Ivanhoe Reservoir and the other at the spreading grounds of the Los Angeles River supply, with chlorine gas injected into the mud and sand under heavy growths of *Potamogeton.* Chlorine bleached and killed adult plants but root buds germinated subsequently. The chief drawback to to the use of chlorine gas is the difficulty of applying the chemical to the exact spots needing treatment.

Chlorinated Hydrocarbons

The use of liquid chlorinated hydrocarbons for aquatic weed control was inaugurated by the Cloroben Corporation of New Jersey (7). The first compound is known as Benoclor No. 3 Regular, and is used in treating reservoirs. Miscible Benoclor No. 3 Special and Benoclor No. 3-C are used for running water where tastes and odors are not to be considered. The former,

which is less stable, is immiscible and is used for domestic supplies whereas the latter stands up with better emulsification for use in irrigation reservoirs and ditches. New types are being developed to minimize taste problems.

Benoclors which are "still" runs of chlorinated benzene are mainly trichlorinated benzenes. They have a pungent odor, are non-corrosive, non-inflammable, non-toxic, relatively heavy (sp. gr. 1.45) and are sprayed under water, which produces a white milky cloud. Plants readily absorb and adsorb the chemical with great avidity and translocate it to vital parts. The leaves deteriorate and the cloroplasts dissolve into the oil of the chemical applied. Within 24 hours plants collapse and in four to five days turn white. Animal life is destroyed, provided it does not get out of the way of the advancing treatment.

Aquatic weeds vary in their response to Benoclor treatment. *Chara* and "water weed" are two types that are easily killed. Sago pondweed, coontail moss, horned pondweed and water milfoil are intermediate in response. Parrot feather requires a surface spray only at a rate of 500 gal. per acre. The emergent weeds are more difficult when treated with Benoclor. Cattails and tules have been killed when previously cut beneath the surface of the water. Yellow water weed, ditch grass (*Paspalum distichum*), sedges and rushes have been killed, but higher dosages are required for them.

Application of Chlorinated Hydrocarbons

Chlorinated hydrocarbons are applied as a spray either from a fixed point into a canal where it treats the water passing by or from spray equipment on boats treating reservoirs or lakes. Any type of pump and air compressor is suitable (ordinarily 1½-hp. air-cooled gasoline engine directly connected to a 3-gpm. Viking pump), provided the size, type and number of nozzles are selected which will give a reasonable degree of dispersion for the quantity which should be applied per unit of time.

Nozzles with screened openings 0.02 to 0.04 in. (Spray Equipment Co.) are ordinarily spaced 2 ft. apart. Preferably, the chemical should be sprayed about 1 ft. above the tops of the submerged weeds, and at least 4 in. below the water surface. The approximate dose for lakes is 15–50 gal. per acre. Present practice in treating irrigation ditches has been greatly modified. First, the water level is lowered to a minimum. Second, the first treating station is selected 750 ft. upstream from the infested area. Third, in a ditch with a top width of 12 ft. and a bottom width of 7 ft., a dose of about 11 gal. per mile is used, with two-thirds being applied at the first station and continued for one hour. Fourth, a second station is started ½ mile downstream to reinforce the chemical blanket to its original intensity, usually taking about one-sixth of the total dose. Fifth, a third station another ½ mile downstream repeats the same process. Such a treatment cleans 2 miles of ditch. Water so treated may be disposed of by dilution into a larger canal, by being run to waste or by absorption by a mile or more of untreated ditch before it is used for irrigation purposes. The exact dose per mile obviously depends upon the amount of weed growth present, type of soil and other factors. *Anacharis* has been killed with 1,000 ppm. of Benoclor applied for one hour, or 4,000 ppm. applied for fifteen minutes. A balance must be established

between the dose concentration and the contact period allowed.

Toxicity

Benoclor is not toxic to birds or animals (8). Livestock refrain from drinking water containing noticeable amounts of Benoclor, and animals which drink water containing sufficient amounts of Benoclor to taste appear not to be affected. Benoclor will kill fish if care is not taken in the application of the chemical. In lakes and reservoirs, the Benoclor should be treated from the shore outwards in such a way that it will not trap fish in coves or sections of shallow water. In some instances, the growth near the shore line can be cut, thereby scaring the fish to deeper water. Benoclor is toxic to crayfish and clams. It has no effect on human beings, and quantities of water containing a high concentration appear not to be too objectionable from the standpoint of taste and odor. The aromatic, or medicinal, odor is not overly objectionable and in high dilutions Benoclor gives the water a "clean" taste.

Los Angeles Experience

Benoclor has been used at Dry Canyon and Bouquet reservoirs on a growth of *Potamogeton pectinatus*. Original failures were due to the use of dosage rates which later proved too low. The record based on data furnished by H. F. Cahill, Superintendent of the Los Angeles Aqueduct, Southern Division, is as follows:

Dry Canyon Reservoir (Capacity, 440 mil.gal.; area, 59 acres)

November 1942—100 gal. were used on marginal treatment at a rate of 18 gal. per acre. The outflow was 301 fps. Results were negative.

Dec. 6, 1942—100 gal. were added to the east cove at the rate of 15 gal. per acre. The reservoir had been bypassed with no outflow. The kill was about 50 per cent. On this occasion, owing to the density of the weeds, 28 fish, 2 to 4 in. in length, mostly carp, were killed.

June 1943—Experiments were made on four separate square plots on the submerged portions of the dam, using 2 gal. per plot, or approximately 30 gal. per acre. The flow through the reservoir was 476 fps. The center plot had a 75 per cent kill, but the plots nearest moving water were less successful, clearly showing the effect of dilution.

Aug. 27–September 1943—The main coves of the entire reservoir were treated, wherever visible growths could be detected, with a dose of 35 gal. per acre. Results were good in all water shallower than 8 ft. Beyond this depth the percentage of kill decreased rapidly as the water deepened. Tastes were observed by consumers taking water directly from this reservoir for a period of 48 hours following each treatment. The complainers were not adamant; in fact, they were somewhat apologetic; nevertheless, they were justified. The fact that some of the chemical reached them indicated that dispersion was excessive.

June 21–28, 1945. The growths in deep water nearest the channel and near the upper end were found to be as bad as ever, and 150 gal. were added at a rate of 40 gal. per acre. The maximum amount added per day was 50 gal. This was reduced to 35 gpd., and finally to 15 gpd. Complaints were still received, even with the 15-gpd. application, and treatment was terminated to stop further complaints.

Experience definitely proved that the original dosage rate of 15 gal. per acre,

as recommended by the manufacturer's representative, was too low. The author feels that a dosage rate of 50 gal. per acre would have produced better results. The second lesson gained by this experience was that any domestic reservoir treated with Benoclor should be bypassed and no dilution be permitted for three to four days.

Bouquet Reservoir (Capacity, 5,100 mil.gal.; area, 420 acres)

This reservoir had a very heavy growth at the northeast end in water up to 40 ft. in depth, and patches were spotted along most of the entire shore line.

July 1–22, 1943. A dose of 35 gal. per acre was applied to the entire shore line where weeds were found. The total amount of chemical used was 600 gal. The reservoir had no water flowing in or out. The kill was 90 per cent, with a noticeable improvement in the shallow areas over the steeper banks.

Sept. 20–22, 1943. With the reservoir 4 ft. lower, 150 gal. of chemical was used on patches which were too deep to reach during the July treatment. The dose of 35 gal. per acre was only approximated. The kill was about 90 per cent.

While some of the spots were completely eliminated, the area which had been the worst was, by September 1945, rapidly nearing its original condition. This may be due in part to the fact that both treatments were made with the water level 15–20 ft. below normal, and weeds rooted or seeded above the treated line had a chance to grow as soon as the reservoir water level was brought back to normal. It was observed that some of the original growths occurred in water which was normally 35 ft. deep.

Irvine Ranch Experience—Peter's Lake (Capacity, 330 mil.gal.; area, 64 acres)

Peter's Lake is an irrigation reservoir with no domestic use. The main growth was *Potamogeton pectinatus*, along the shore line principally, which was so thick that a row boat could not be oared through it. There was a secondary growth of *Chara*. A special hand paddle boat had to be rigged up for treating purposes.

Late Summer 1944. During the late summer, 75 gal. of Benoclor was added on test areas along the shore with a dose set at 45 gal. per acre. The kill was over 90 per cent but, because the weeds had already flowered and had dropped their seed, it was decided to postpone general treatment until the following spring.

June–July 1945. With the growth not yet up to the water surface, 250 gal. of chemical were added at an exact rate of 50 gal. per acre up to water depths of 16–18 ft. Previously, the chemical had been added just barely below the surface. The second treatment was made by lowering the nozzles right down to a foot above the growing tops. The kill, as observed by the author on Sept. 13, 1945, was remarkable. An estimate of 95 per cent is conservative. One cove appeared not to have been as carefully treated as the rest of the shore line. No check was made on tastes and odors. About 10 lb. of fish were killed because of their apparent inability to remove themselves from entangled growths as chemicals were applied. The growth of *Chara* was killed with a dose of 15 gal. per acre. Scattered *Chara*, patches of minor consequence, were observed returning.

The chief lessons of this experience are:

(1) *Potamogeton pectinatus,* which is one of the most difficult of all weeds to control, can definitely be killed by a Benoclor dose of 50 gal. per acre when accurately applied over the plants in the growing season before flowers set.

(2) Dilution with new water must be kept to a minimum, and at least four days' storage is desirable.

(3) Roots of the growths were thought to have been killed, which up to this time had not been accomplished.

Imperial Valley

In 1943 test runs were made at Blythe and Yuma, and by the Imperial Irrigation District in Imperial Valley to work out operating procedures to use Benoclor for keeping irrigation ditches clean (9). The Imperial Valley Irrigation District services over 3,000 miles of canals and irrigation ditches, covering over 400,000 acres of irrigated land. A canal, six miles in length, which had overflowed at 45 fps., when it should have safely carried 100 fps., was selected for treatment. The flow was reduced to 10 fps. and run to waste, while a six-hour treatment was made. The water level dropped 1½ ft. Roots, however, were not killed, and it was claimed that treatments were only to delay or retard growth with gradual reduction of aftergrowths following treatments during the growing seasons. To date about 5,000 gal. of Benoclor per year have been used in Imperial Valley.

Salt River Valley

The Salt River Valley Irrigation Districts irrigate over 340,000 acres. About 3,500 gal. per year are used in ditch weed control. Richard Bennett, City Engineer of Phoenix, in response to inquiries of the author, substantiates the following:

1. Benoclor is beneficial for algae, moss and rabbit's foot grass.

2. Benoclor does not kill the roots of all the *Potamogeton* plants (at least so far as the short method of treatment is concerned).

3. There is no adverse effect on the lands irrigated.

4. Some of the worst canals are treated six to eight weeks apart, but the average control is 2½ months in length.

5. Because of the high cost of chemicals, treatment is restricted to small distributing ditches with mechanical methods still being employed on the larger canals.

6. Water star grass, which is particularly bad in local canals, has been killed (including the root system) by exceedingly heavy Benoclor doses in standing sections with two hours' contact.

It would appear that still heavier chemical doses or longer contact periods should be tried out in place of treating every six to eight weeks in an effort to attack root systems more vigorously. It would also appear that the continual reseeding from the growths in the main canal, together with the growths from broken sections caused by mechanical cleaning in the main canals, indicates that sooner or later the source of the trouble itself must be eliminated by chemical treatment of the main canals themselves. It is said that the present high cost of the chemicals prevents this being considered. Yet, it is obvious that treatment in this instance should start at the Stewart Mountain Detention Dam, where growths are prolific. They do not cause trouble so far as operation is concerned at this location, but are the main source of seed and sprouting in lateral ditches.

Winslow

The Santa Fe Railroad operates a six-mile ditch near Winslow for an engine water supply. Weeds became so prolific that the carrying capacity was seriously affected. After several unsuccessful attempts to regain capacity by treating with copper sulfate, George Davenport, Water Supply Engineer for the Santa Fe Railroad Company, during July 1945, used 100 gal. of Benoclor. Sufficient capacity of the ditch was restored to meet the existing emergency.

Yakima, Wash., U.S. Bureau of Reclamation, Tieton Division

A test run was made in June 1945 on five miles of ditch, using 50 gal. of Benoclor with one-hour contact. Of this amount, 30 gal. were added at the first station and 20 gal. at a second station, one mile downstream. The growth was largely "water weed," with some sago pondweed. Results are said to have been good.

Miscellaneous

Distributors for Cloroben state that there has been interested use of this chemical by various irrigation companies in New Mexico, Texas, Utah and Washington. In California it has been adopted by the Miller & Lux Land Company in San Joaquin Valley, and by Irrigation Districts in Modesto and Turlock. The Montana Fish & Game Commission employs Benoclor to make surveys of non-game fish.

A review of the literature indicates that Benoclor has been used at a number of locations, as follows:

1. *Echo Lake near Westfield, N.J.* (10). Treatment was administered to minimize water weeds for the benefit of boating and bathing with doses varying from 12 to 14 gal. per acre. Studies indicated considerable improvement in odor reduction four to six days after treatment.

2. *Cranberry Lake, Sussex County, N.J.* (11). Treatment was administered to clear up the lake from excessive water weeds, largely *Potamogeton robbinsii,* which resulted in improved fishing conditions for the public. This lake covers 195 acres, 15 per cent of which was so overgrown with liliaceous vegetation as to be unnavigable. At least 35 acres were treated with reasonable success with an application of 750 gal. of chemical at a cost of $3,000.

Economics Involved

Chemical treatment of land, emergent and water weeds is economically justified. Probably the most expensive chemicals for land weeds are the 2,4-D compounds. It is estimated that the cost per acre per one application, using retail prices, is $10.00 an acre, but if raw materials are purchased and mixed it may not exceed $5.00 per acre. An estimate for chemically treating a 500-ft. strip around 1,199 electric transmission line towers with Nox-Weed was received from a bidder quoting $32,000 for chemicals at 17¢ per gallon, or $6.00 per acre, and $34,500 for labor in difficult terrain requiring 237 days.

The mechanical costs of removing cattails, tules and other emergent growths from canals vary from $1,000 to $2,000 per mile. Mechanical cleaning and dredging involves interruption of service, gives but temporary relief and often accelerates reseeding and rerooting. Chemical treatment is far cheaper and less cumbersome.

Mechanical cleaning of canals and ditches to remove aquatic growths below the water line varies from $150 to $600 per mile. Chemical treatment, on the other hand, is about $30 per mile

per treatment. On a yearly basis, the total cost is $50 per mile, which is a fraction of that for mechanical cleaning.

The cost of treating reservoirs with Benoclor at $2.75 per gal. is high, amounting to $137.50 per acre. This is over twenty-five times the cost for land weed control with 2,4-D compounds. One justification for the high cost of Benoclor is that so far there has been only a limited use of it, and, until the quantity used increases, production cost in all probability cannot be lessened. Ortho-dichlorbenzene, which in preliminary results may be 80 per cent as efficient as Benoclor, costs only $40 per acre. The use of this material, however, would be an infringement on patent rights. Undoubtedly chemical costs for aquatic weed control may be expected to be reduced as the demand for chlorinated carbons increases.

Evaluation of Problems Involved

Successful weed control for land, emergent and water weeds requires:

1. Accurate identification of vegetation to be controlled.
2. Knowledge of budding, blossoming, fruiting and environmental habits.
3. Recognition of stage of growth of plants present.
4. Selection of chemical best suited for each type of plant, and decision whether soil should or should not be sterilized.
5. Determination of dose and time of contact.
6. Consideration of dilution and storage factors where aquatic growths are concerned.
7. Consideration of type of soil and density of growth, and in the case of water weeds the mineral quality of the water and nature of the soil underlying the water.
8. Accurate application of chemicals with proper wetting, emulsifying or spreading agents, and in the case of water weeds the placing of the chemicals directly over plant tops.
9. Attention to all hazards, such as toxicity to man and animals and fire and handling hazards.
10. Preventive measures to conserve fish life.
11. Determination of resistivity built up by specific types of plants after repeated treatments with the same chemical.
12. Consideration in the case of water weeds of water movement and limnological factors.
13. Proper housekeeping methods in cleaning up debris after treatments have killed the plants.
14. Careful application to avoid tastes and odors in domestic supplies, both surface and subsurface, and before and after subsequent chlorination.
15. Taking of photographs and keeping of accurate records on treatment results.
16. Conducting chemical examinations to trace residual chemicals in the water supply, resulting from land or water treatment for weed control.
17. Patience and persistence in following up with subsequent treatments.
18. Rigid control of specifications of chemicals used, particularly in reference to impurities which may cause odors in water supplies.

Conclusions

Land and water weeds can be economically controlled by the use of chemicals, provided such work is properly supervised and intelligently applied.

Land weeds and water emergent weeds are generally best controlled by the new 2,4-D compounds, but other

chemicals have specific advantages for different purposes.

Submerged aquatic weeds are generally best controlled with chlorinated hydrocarbons, employing higher doses than previously recommended (up to 50 gal. per acre), allowing much longer contact periods (up to four days) than formerly, and by observing necessary factors to avoid complaints of odors and tastes from consumers.

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Public Relations in Water Works Management

By *Max K. Jones*

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Presented on Nov. 15, 1945, at the West Virginia Section Meeting, Wheeling, W.Va.

THE term "public relations" is a very glittering and popular phrase at this time, and we all know that the character who was known as the "Advance Man" for the circus when we were boys now calls himself "public relations counselor" and has a very fancy business card. For the purposes of this paper, however, the phrase "public relations" involves the contacts of a business organization or any other kind of group of activity, or an individual himself, with the public, the employees, and, if there are any, the owners of the business, or, in the case of a non-profit or charity organization, those who furnish the funds.

Attention here will be directed to public relations as they affect a water department or a water company. There is little, if any, difference between the two types of water works operation and the author's intention is to make no distinction except to say that when speaking of owners of the business it would mean, for a publicly owned water works, the taxpayers and voters of that community, whereas for a privately owned water company it would mean the common stockholders.

The water works industry has three groups of people who are directly affected by its operation. These are, and not necessarily in the order of their importance, the customers, or the general public; employees who work in the business, and the owners, who, as previously noted, may be stockholders or taxpayers. In the case of a publicly owned enterprise the taxpayer and the customer are more or less the same group. Nevertheless, they approach the problem of the water works and its service to them with a different frame of mind, depending upon whether at the moment they are taxpayer conscious or customer conscious.

Any approach to public relations starts with the word "information"—what our friends in the City Room call "news," but not necessarily newspaper stories. Peoples' convictions cannot rise above their understanding; therefore, if it is your desire to have sound harmonious public relations, you must secure an understanding of your operation by the three groups just described. An understanding or knowledge of your operation, its problems, aims and policies, can be secured only by the dissemination of information.

Different types of information must be put before each different group. For instance, the employee group is actively interested in information which affects the job. The employee wants to know, and is entitled to know, what your rules and regulations are. What are the chances for advancement or promotion? What are your sick leave provisions? Will he be protected by group insurance in the case of his demise? Will he have a pension when he is old, tired and desirous of retiring?

A sound personnel relationship between the employer and the employees is a part of good public relations. It has been proven time and time again that an organization cannot maintain a sound public relations standing in the community unless it has an equally satisfactory relationship with the employees who make the product or produce the service. Modern and effective personnel policies are, therefore, a part of the development of any overall public relations program.

Our object in the water works business is to convince the customer that the water he receives is pure and wholesome, that it is abundant and that the water system serving him is in a position to take care of his needs now and in the future. To do this, the best public relations tool known is sound publicity. By that is meant stories in the daily newspapers, for every water organization is the source of excellent news material. Another way to do it is to throw open the plant, invite the public to inspect it and to learn more at first hand about this vital service.

The author has played host to a civic group at a large luncheon served in the boiler room, with the speaking program at the conclusion of the luncheon being broadcast over the local radio station. There are few business leaders in town who have not visited the water works plant and seen the whole operation under expert and instructive guidance.

To be more specific about newspaper publicity, here are a few types of good stories. Take one of the key jobs for instance, such as your chemists. Tell the story of the chemist and what he does and what his responsibility is in helping to maintain a pure and wholesome supply of water. This is what newspapermen call a "feature" story. It is a good type of news story and you will find that your local paper will be glad to publish it. Your chief engineer or man in charge of the distribution system, even an interview with a meter reader, can be made intensely interesting. Of course, you must always give public information through the press on new developments which affect the water works. The installation of new pumping equipment, the construction of new filters, and the installation of additional mains are always news in any community. News should be accurately and promptly placed before the public in the medium they are accustomed to use. There is only one such medium and that is the daily newspaper.

Radio always plays its part in any public information program which is part of the general public relations policy. Many different kinds of radio features have been sponsored. For example, certain companies associated with the author's organization have assumed sponsorship in the broadcasting of games played by local athletic teams, such as the high school basketball team. They have used their commercial time to acquaint the public with the advantages of a complete and intelligent use of their water service. Another company has sponsored the local weather broadcast and, of course, there are many other methods in which radio can be employed to advance the public relations standing of your enterprise.

The author is a firm believer in the value of newspaper advertising, particularly that which is largely of an institutional and informational character. You may ask: Why should a water works plant advertise—our market is assured and we have nothing to sell? Why bother with it? But you do have

something to sell. There are periods of the year when you can use your advertising space to increase the use of your product. Lawn and garden sprinkling is a fertile field for increased domestic use. A continual reference to the desirability of personal cleanliness by greater use of baths is also a way to build up the load gradually. Then too, the use of advertising space can be most effective in putting before the public types of information about your operation which do not come under the head of news. This type of advertising is usually known as "institutional."

As regards the owners of the business, the stockholders or taxpayers, they are entitled to adequate information concerning the financial results of your operation. More and more, municipal water works operations are issuing public annual reports, indicating how and where the money was spent to provide the public with service. It is good business to keep the owners adequately informed, because when additional capital is needed it is this group that must supply the funds that you require. If they are not informed, it will be more difficult to secure the capital. The author has no experience in municipal operation, but it would seem to him that the publicly owned water works that had gone to the trouble of keeping the taxpayers advised as to its operating results and financial standing would have less difficulty in securing from those same taxpayers consent to spend the money that is needed to provide new or better facilities or additions to the plant.

Any one of the three groups above mentioned can make your operation so unpopular that your day-to-day duties will be, to say the least, most complicated and discouraging. If your employees do not like you and are dissatisfied and unco-operative, your job will be unpleasant. If the customers think your service is poor and have no conception of your problem, then, too, your life will not be a happy one; and finally, if you are cramped for funds and unable to secure modern, efficient equipment or to make the extensions that are required, your day-to-day business affairs will be of the type that brings lines to the forehead and silver streaks to the hair.

A sound approach to the problem of maintaining, generating and then extending a sound public relations standing for your particular enterprise may be obtained in the following way. First, study your problem. Where are you weakest? What phase of your public relations problem should be first attacked? Second, having developed your problem and having determined your objectives, go to work and from time to time pause to study the results obtained. Third, do not become discouraged after a year or two of time and effort devoted to securing a better public relations standing. It takes time for any organization to "win friends and influence people." It cannot be done overnight; it is a 24-hour-a-day, 52-weeks-a-year job. And, finally, as you embark on a plan of public relations, try to get everyone you can on your team. The group that will help you most at first are your employees, but a few influential members of the other two groups—the public and owners—will help beyond measure.

Conservation of Municipal Water Supplies in Air-Conditioning Systems

By N. C. Ebaugh

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Presented on Nov. 16, 1945, at the Florida Section Meeting, Miami Beach, Fla.

THE average person drinks about 4 lb. of water, eats about 4 lb. of food and breathes 32 lb. of air per day. Members of the Association are well aware of the careful supervision which municipal water supplies receive with respect to cleanliness and purity. The 4 lb. of food are carefully regulated under federal, state and city pure food laws and inspections. The 32 lb. of air, however, have received very little attention thus far in man's existence.

The purpose of this paper is to explain briefly the usual summer air-conditioning systems, to point out the water problems which these systems may create and, finally, to suggest ways of solving these water problems so as to conserve municipal supplies and protect the disposal systems.

What Is Air-Conditioning?

Air-conditioning is the processing of air with respect to the control of its temperature, moisture content, cleanliness (with respect to dust, bacteria and odors), and movement within an enclosure.

If these factors are controlled at all seasons of the year, then the system is known as a year-around air-conditioning system. If only cooling, the removal of moisture and the control of air quality and movement are practiced, then it is only a summer air-conditioning system.

Business establishments have learned that a good return on the money invested in air-conditioning systems is possible. We may expect increased use, particularly of summer air-conditioning, in hotels, trains, buses, clothing and department stores, beauty parlors, banks, theaters, restaurants, office buildings, grocery stores and similar establishments where the investment in air-conditioning equipment is soon recovered by increased business. The public is becoming educated to expect comfortable conditions in summer just as they have been educated during the past 50 years to expect comfortable conditions in winter.

Importance of Water Supply

The essential elements of the most commonly used summer air-conditioning system are shown in Fig. 1. Referring to this figure, a mixture of outside air and return air from the conditioned space is cleaned in the filter, cooled and dehumidified in the cooling coil and then distributed to the conditioned space. Heat and moisture, at low temperature, are extracted from the air to be conditioned, and this same heat, plus the work required to drive the compressor, is thrown away at a higher temperature level in the condenser. The condenser is cooled in all but small capacity systems with the aid of water. Figure 1 shows that the

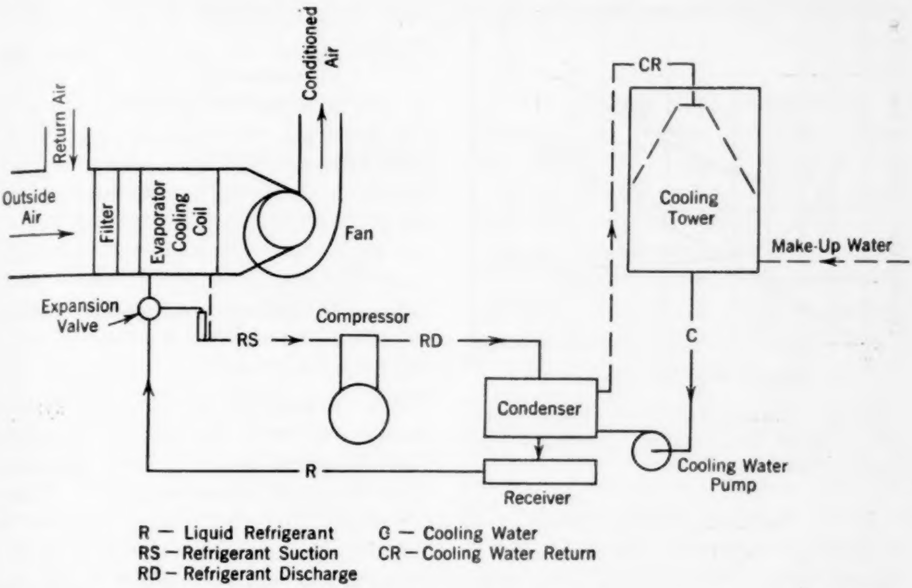


FIG. 1. Air-Conditioning System, Showing Conditioner, Refrigeration System and Cooling Tower

cooling water is recirculated through the cooling tower where the heat is ultimately given off to the atmosphere.

Water Problems Created

Many small systems use water cooled condensers without the cooling tower, and this leads to difficulty. There may not be adequate water main capacities in congested business areas to permit large quantities of cooling water to be used in air-conditioning systems. Furthermore, this water usage comes at a time in the summer when other water usage is likely to be at its peak. This might mean that a very much greater water plant capacity would be required to meet this short-time peak demand. Also, if the plant and the distribution system can take care of this increased load, there is still the problem of disposal. Certainly it would be undesirable to throw large amounts of cooling water into the sanitary sewer systems, and in many cities the storm sewer systems may be inadequate to handle such loads during periods of heavy rainfall.

Letters were sent to several of the larger cities in Florida and to some others out of the state in an effort to ascertain what was being done about water supply and disposal for air-conditioning systems.

City Manager and Acting City Engineer of Miami Beach, Fla., Claude A. Renshaw, replied: ". . . since all the water which enters our sanitary sewers has to be pumped, we prohibit the connection of waste water from air-conditioning systems to our sanitary sewers if the unit in question uses more than 2 gpm. of water.

"If a city storm sewer is conveniently located, we grant a permit to connect with same. Otherwise, a drainage well is used for the waste water disposal."

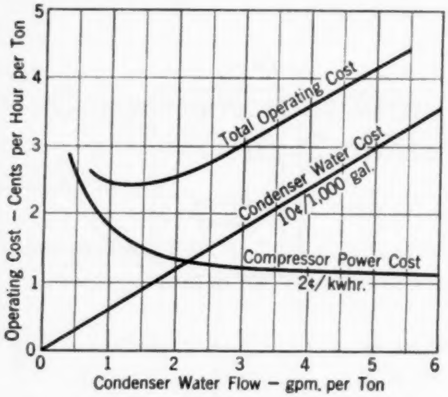


FIG. 2. Variation of Total Hourly Operating Cost of Refrigeration System for Purchased Water and Power

H. L. Schaller, Chief, Division of Plumbing Inspection for the city of Miami, states: "Had we failed to regulate air-conditioning, laundries, ice plants, milk plants and other places from which large quantities of waste water are obtained, we would have rivers in place of streets and buildings would be sewage flooded. Now, with a proposed sewage plant in the picture for sanitary wastes, the picture is again changed. Not only have we a problem caring for the wastes mentioned, but rain water presents another equally pressing problem." Schaller further states that Miami had an ordinance regulating air-conditioning water supply from either the water supply or from wells, dating back more than ten years.

Superintendent of the Tampa, Fla., water department, John S. Long, replied: "There are a number of air-conditioning systems in this city that use city water, and, while the smaller ones dispose of the water by emptying it into the sewers [sanitary], the larger ones, where the volume of water is considerable, use cooling towers and re-use the water.

TABLE 1

Proper Amount of Condenser Water for Minimum Cost—gpm. per Ton of Refrigeration

Cost of Water ¢ per 1,000 gal.	*Cost of Power ¢ per kwhr.* (1)	(2)	(3)
5	1.5	1.75	2.5
10	1.0	1.5	1.6
20	0.75	1.0	1.1

Note: These values apply when both water and power are purchased.

". . . a large air-conditioning system would use such an amount of water that it would be far more expensive than by using a cooling tower. There are other air-conditioning systems in the city that use well water and the disposal of this water is usually taken care of as above mentioned.

"At the present time the city is planning the construction of a new sewer system and there will be sewer charges assessed for the use of the sewers, depending on the amount of water discharged, and when that time comes there will undoubtedly be a survey made and a revision of ordinances to suit."

W. E. Sheddan, City Engineer of Jacksonville, stated: "The city has no special ordinances or provisions for handling air-conditioning problems. Each system installed is worked out on its merits and only permitted when sufficient sewerage facilities are available for disposal of the waste water.

"As far as I know, there have been no serious difficulties to date from an insufficient water supply at any location where the systems have been installed.

"It is to be noted that a number of the installations have sunk their own wells to provide a water supply for this purpose."

Superintendent of the Water Division, District of Columbia, H. Beckett, replied: ". . . all applications to install air-conditioning systems requiring up to 15 gpm. of water are approved and the approval of systems requiring greater amounts of water is governed by the results of flow tests made by the Water Division to determine how the draft of the concerned amount of water would affect the adjacent water distribution system.

"There is no ordinance limiting the use of sewers for disposal of water from air-conditioning systems."

Assistant City Engineer of Chicago, Loran D. Gayton, stated that there were no restrictions on the use of city water for air-conditioning.

These replies show that air-conditioning is creating both a supply and a disposal problem.

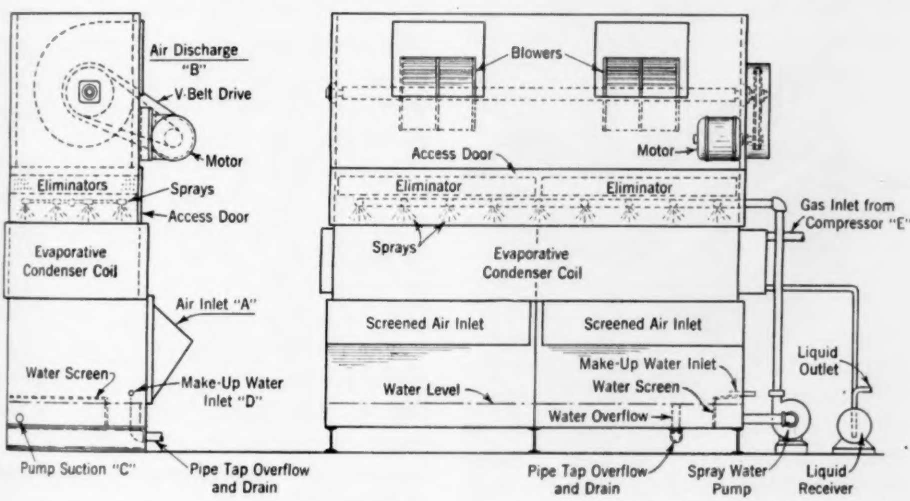
How to Save Water

Small capacity cooling systems of one or two tons of refrigeration (these require about 1½ hp. per ton to drive the compressors) can be purchased with air-cooled condensers. If this is done, there will be no cooling water used.

As a rule, for small installations, in the range of one to ten tons of refrigeration, the cheapest installation is a self-contained unit. These packaged units require only power, water and drain connections to place them in service. If the city water mains and sewers can handle these loads, then the proper amount of water to use depends upon the relative price of water and power.

Examination of Fig. 2 shows that as more water is used through the condenser, the compressor power cost is lower. The water flow for 10¢ per 1,000 gal. of water and 2¢ per kwhr. of power should be adjusted for about 1½ gpm. per ton of refrigerating capacity. If this is done, the owner will have the lowest over-all operating cost. Any larger amount of water flow will be wasteful and result in a higher over-all operating cost.

Table 1 gives the proper amount of condenser water which should be used for various power and water costs.



Adapted from drawing by the Trane Co.

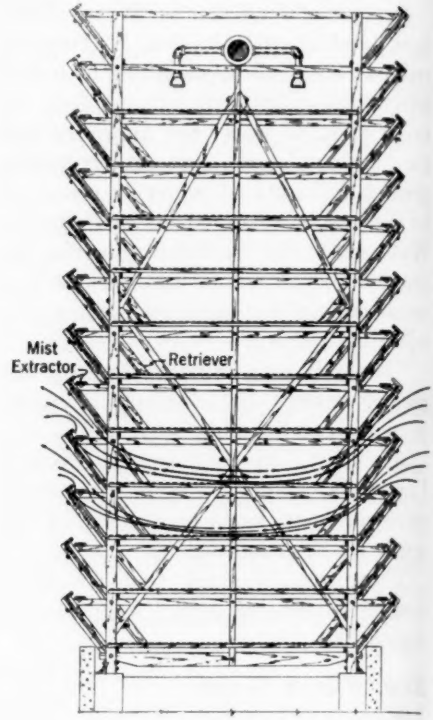
FIG. 3. Evaporative Condenser, Showing Condenser Coil, Water Circulating System and Fans for Pumping Cooling Air

The water flow to air-conditioning systems should be adjusted in accordance with these quantities.

Control of the water flow in accordance with Table 1 will not only result in the conservation of water in most cases, but it would also make a friend of the customer, since he will have a minimum operating expense for water and power combined.

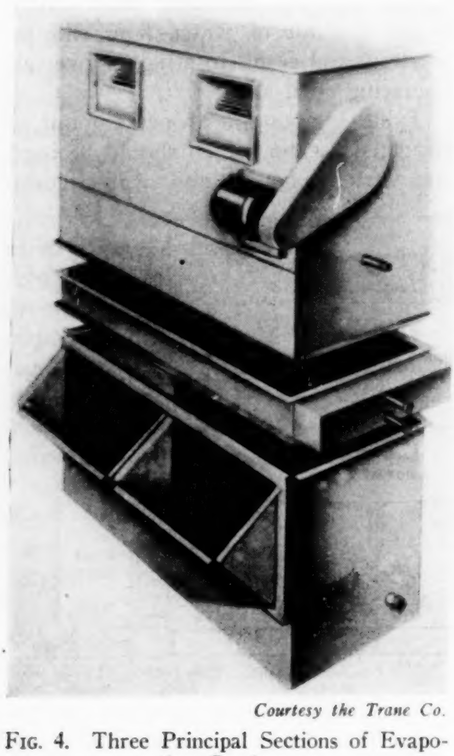
Water Too Expensive to Throw Away

The illustration shown in Fig. 2 used a water cost of 10¢ per 1,000 gal. This is a lower cost than is usual in most cities and was purposely used to show that even with this low cost it pays to adjust the flow. *The plain fact is that city water is too expensive to use as a cooling medium.* The low first cost of the package type of air-conditioner frequently attracts customers who overlook the operating costs which go on year after year.



Courtesy J. F. Pritchard & Co.

Fig. 5. Cross-Section of Atmospheric Cooling Tower, Showing Water Distributors, Splash Decks and Louvers to Prevent Excessive Wind Drift

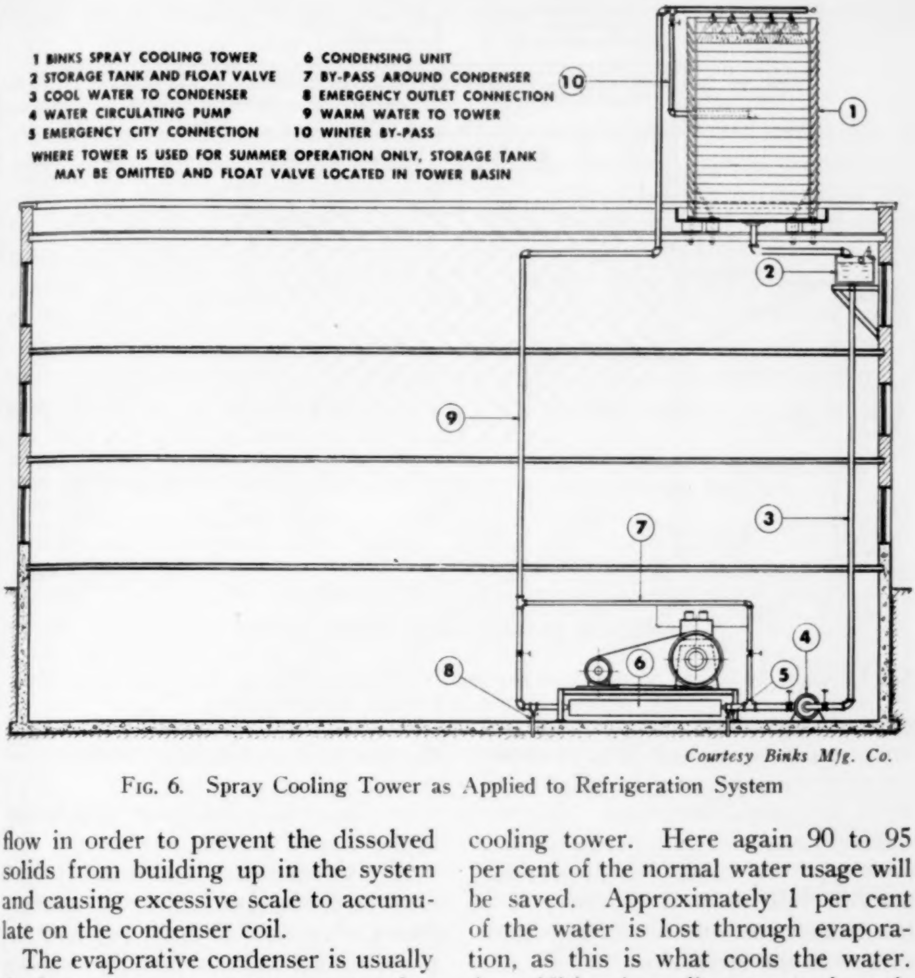


Courtesy the Trane Co.

Fig. 4. Three Principal Sections of Evaporative Condensers

Approximately 90 to 95 per cent of the water used in the cooling of the refrigeration condensers may be saved by means of evaporative condensers or by recirculating the water through a spray pond or cooling tower.

The essential elements of the evaporative condenser are shown in Figs. 3 and 4. This device saves most of the water by recirculating it over the condenser coil. Approximately 1 per cent of the water will be lost through evaporation and an additional several per cent should be wasted through the over-



Courtesy Binks Mfg. Co.

FIG. 6. Spray Cooling Tower as Applied to Refrigeration System

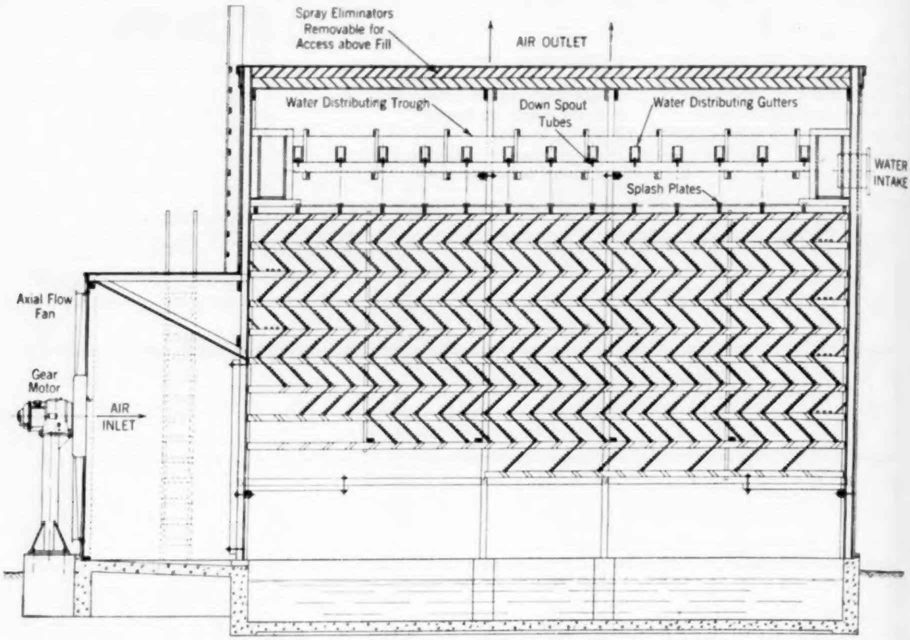
flow in order to prevent the dissolved solids from building up in the system and causing excessive scale to accumulate on the condenser coil.

The evaporative condenser is usually the best answer to water conservation from the standpoint of initial cost and operating expense. It has the disadvantage of higher first cost and the requirements for space. Frequently it may be located on the roof or in a basement area. In the latter case, the fans in the condenser can be discharged to the outside, thus making the unit useful in ventilating the engine room and basement areas.

Water Cooling Devices

As shown in Fig. 1, the condenser water may be recirculated through a cooling tower. Here again 90 to 95 per cent of the normal water usage will be saved. Approximately 1 per cent of the water is lost through evaporation, as this is what cools the water. An additional small amount, depending upon the type of cooling tower, will be lost through wind driftage during high winds and several per cent should be wasted to the overflow in order to prevent the building up of dissolved mineral matter in the water.

Cooling towers are of three general types: atmospheric, spray and mechanical draft. Figure 5 is an illustration of an atmospheric tower. The warm condenser water is introduced through a distributing system at the top of the tower and it splashes down to each successive deck as it is cooled. The



Courtesy Foster Wheeler Corp.

FIG. 7. Cross-Section of Forced Draft Cooling Tower, Showing Fan, Tower Packing, Water Distributing System and Spray Eliminators

tower must be located in an exposed position where it can get the full benefit of any wind movement. A spray cooling tower is shown in Fig. 6. This type must be located in an exposed position relative to the wind. It is low in first cost and finds many applications in the small sizes.

Mechanical draft towers may be located in any convenient place, as they depend upon fans for proper amount of air flow for cooling the water. These towers may be of the forced draft variety, such as shown in Fig. 7, or the fans may be located on the air discharge side, such as shown in the induced draft tower of Fig. 8.

Mechanical draft towers are built in all sizes required in air-conditioning systems from the smallest to the largest, and there are many cases where the water may be conserved and the operating cost decreased by converting the system from purchased water to the recirculated type.

It should be pointed out that in the application of cooling towers the rotting of wooden parts and the corrosion of metal parts must be guarded against. Heart redwood and heart red gulf cypress should be used for the wooden parts and heavy hot-dipped galvanized iron or all copper and brass fastenings should be used if the tower is to have reasonable life and is to be safe during high winds. Some cities prohibit the use of wood in the construction of cooling towers due to the fire hazard when located on inaccessible roof areas. In this case all metal towers are allowed.

Determining Proper Amount of Recirculated Water

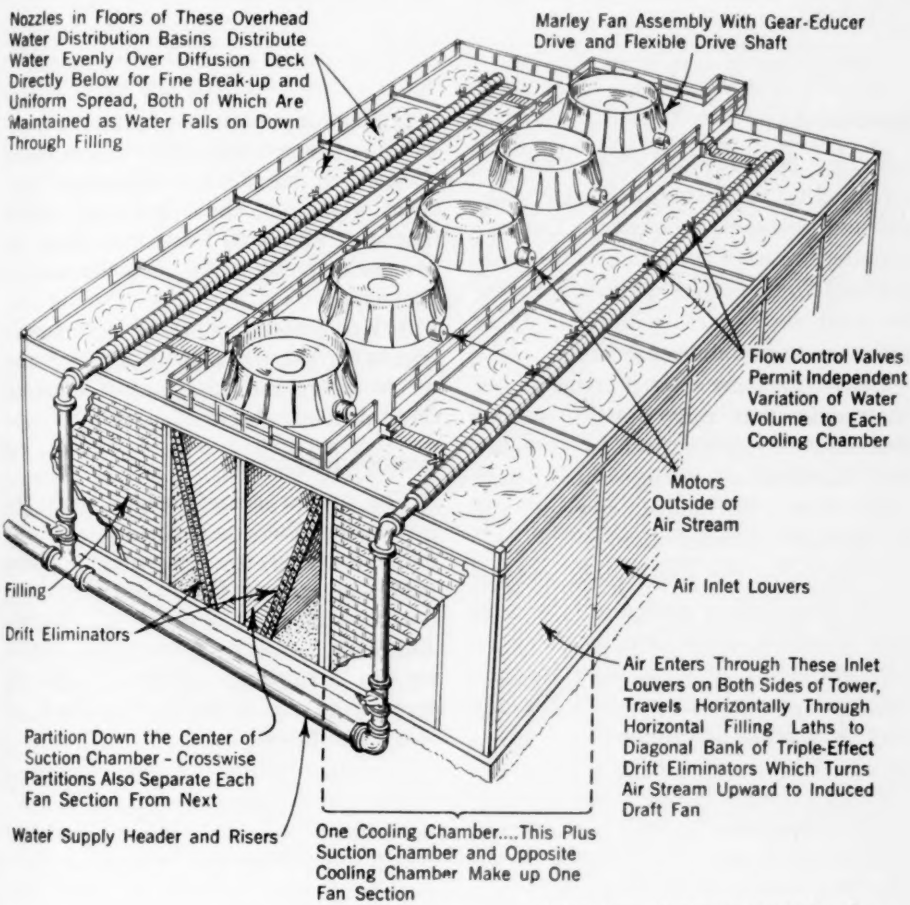
The amount of cooling water required in recirculation systems depends upon the relative cost of pumping the

water over the cooling device, plus the cost of the refrigeration compressor power. As a rule, where atmospheric or mechanical draft towers are allowed, the requirement is between 3 and 4 gpm. per ton of refrigeration (approximately the same as per horsepower of the compressor). Whereas, for spray ponds and spray cooling towers, the amount varies from 4 to 5 gpm. per ton of refrigeration.

A comparison of the various types of water cooling equipment indicating the approximate order of desirability, for some of the important considerations, is given in Table 2.

Well Water May Be Used

In some localities well water may be used for cooling purposes, although in most cities it is safe to say that this should be discouraged, due to the necessity for conservation of water and the disposal problems which result. Where it is possible to use well water, the proper amount is of the same order of magnitude as those stated above for recirculated systems.



Adapted from drawing by the Marley Co.

FIG. 8. Large Induced Draft Cooling Tower

TABLE 2

*Comparison of Various Types of Atmospheric Water Cooling Equipment**
(Figures indicate approximate order of desirability)

	Cooling Pond	Spray Pond	Spray Tower	Deck Tower	Mechanical Draft	Indoor Tower
Cost	x	2	1	3	4	5
Area	5	4	3	2	1	x
Height	1	2	3	4–5	4–5	x
Weight per square foot	x	x	1	3	4	2
Independence of wind velocity	6	3	4	5	1–2	1–2
Drift nuisance	1	6	5	4	2–3	2–3
Make-up water required	1	6	5	4	2–3	2–3
Pumping head	1	2	4	5	3	6
Maintenance	2	1	3	4	5	6
Suitability for congested districts	x	5	4	3	1	2
Water quantity required for definite result	6	5	4	1–2	1–2	3

* From 1943 A. S. H. V. E. *Guide*.

Conclusions

It may be concluded then, that air-conditioning is causing both water supply and disposal problems. The accelerated rate of installing air-conditioning, which may be expected during the next few years, will cause these problems to become more acute.

In view of these facts, it seems proper to suggest that water plant superintendents, in co-operation with other city authorities having jurisdiction over water distribution systems and the disposal systems, should:

1. Examine the water plant and the water distribution system to be sure that complete plans are available so that the ability to serve these increasing loads in various parts of the city may be quickly determined.

2. Examine both the sanitary and storm sewer systems to determine their abilities to handle the increased disposal water and investigate the effect that such increased loads may have on sewage disposal plants now in use or projected.

3. Recommend suitable ordinances regulating the use and disposal of water in air-conditioning systems before these problems become acute.

Acknowledgments

The author acknowledges with appreciation the co-operation of the manufacturers of equipment whose names appear on the illustrations and the assistance of Francis C. Smith, Editor of *Southern Power and Industry,* in furnishing additional illustrations from the author's *Handbook on Air Conditioning.*

Increasing the Sale of Revenue Water

By James W. Myers Jr.

Supt., Kenosha Water Dept., Kenosha, Wis.

Presented on Nov. 13, 1945, at the Wisconsin Section Meeting, Milwaukee, Wis.

THIS paper does not concern itself with expanding markets, as the foregoing title may imply, but rather with the problem of getting paid for all the water that is processed and delivered to existing markets.

The utilities' need for increased revenue to meet the soaring costs of labor and material is without precedent. For example, at Kenosha, utility wages represent 60 per cent of the total operating expense. From 1940 to 1945 the average rate of increase for hourly wage earners was 33.5 per cent and for the salaried employees 28 per cent. The weighted average for the entire water department personnel was 30 per cent. An item closely related to wages is the utility's contribution to the Municipal Retirement Fund, or pension system, which at present is about 11 per cent of the total payroll. These two items, increased wages and pension contributions, represent a 25 per cent increase in the total operating expense.

What the increased cost of materials and supplies will amount to is unpredictable, but, despite price ceilings and governmental control, prices are expected to increase substantially.

Until now, the increase in operating expenses has not been too much of a problem for most utilities because there has been a comparable increase in revenue from war industries. The return to peacetime production, with the consequent loss of war-related revenue, however, does present a grave financial problem to many water utilities.

Since water rates remain fixed, the utility must either file a new rate schedule to meet these soaring costs or it must cast about for other means of increasing its income. Rates, as a general rule, are adequate; and it only remains for management to make sure that the utility receives full payment for the services they are now performing free of charge.

Past and Present Standards of Performance

Many utilities are doing a splendid job in this respect and are accounting for a high percentage of all the water they process and pump. But, by and large, the majority of water utilities can and should do better.

In former days it was common practice for the manager or superintendent of a utility which was accounting for 70 per cent of its pumpage on customers' meters blithely to assume that 15 per cent more was unmetered hydrant use, thereby raising the total to a nice comfortable 85 per cent.

Fortunately, that day is past and no self-respecting water works man will tolerate that kind of arithmetic. Wisconsin water works men have, in general, done a very creditable job and deserve great praise. Recently *Water Works Engineering* discussed the sub-

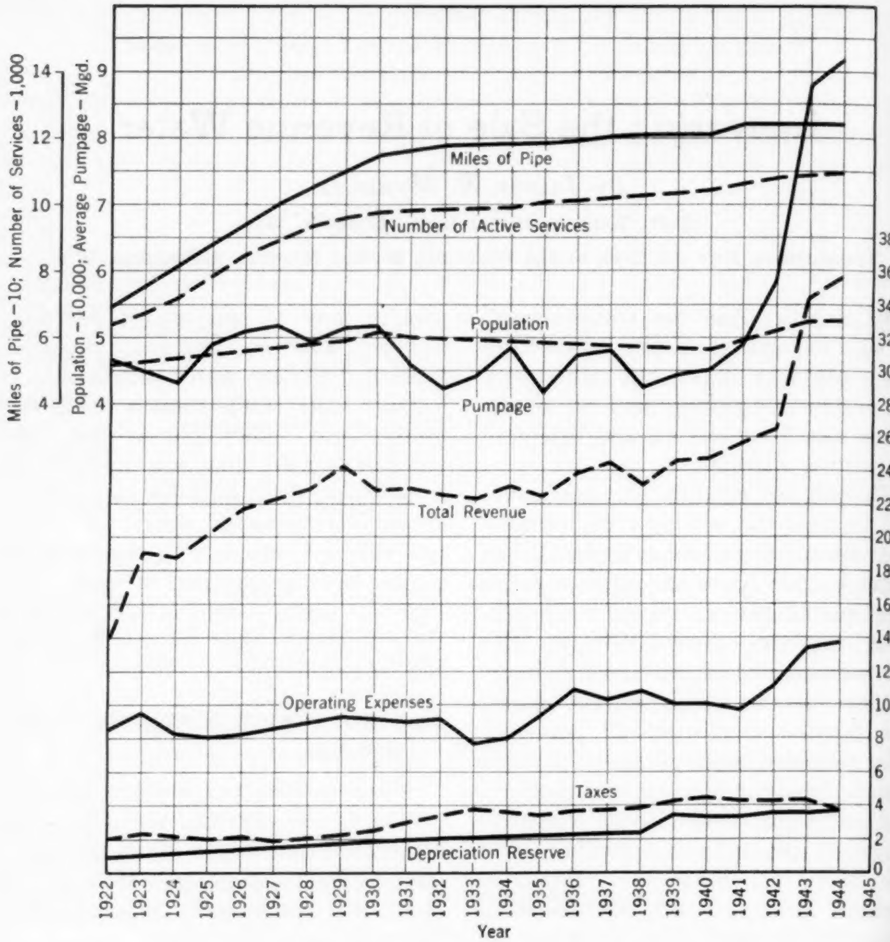


FIG. 1. Chart Showing General Statistics of Kenosha's Water Department

ject of "Accounted-for Water" in its "Round Table" columns. There were 23 contributions to this discussion. Of these, sixteen accounted for 85 per cent or more of their pumpage on customers' meters, three less than 85 per cent and four gave no figures. For obvious reasons all of the contributions could not be published.

Although this poll is too limited to give a true cross-section of the national picture, it does indicate that, despite all the good work that has already been done by many water utilities, there still remain approximately 30 per cent that account for less than 85 per cent of the water they process and pump. This means that there are literally hundreds of utilities that haven't yet achieved the minimum standard of satisfactory performance.

What the ultimate goal should be, in terms of percentage of water accounted for on customers' meters, is a debatable

question, but, in view of present-day meter efficiencies, 92 per cent is not too high a standard to achieve. Several utilities exceed this goal by a comfortable margin; still others account for as little as 43 per cent.

It is recognized, of course, that every community has problems which are peculiar to itself. Consequently, it is manifestly unwise and presumptuous for anyone not knowing all of the local circumstances to set a standard of performance to be attained by all utilities.

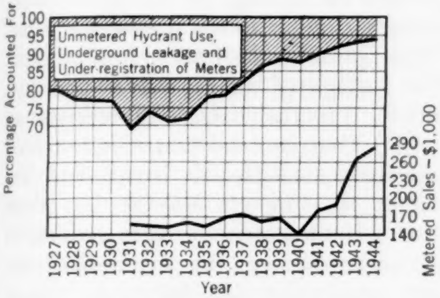


FIG. 2. Chart Showing Percentage of Total Water Accounted for on Customers' Meters and Revenue From Metered Sales

As a result of the efforts at Kenosha to cut losses to a minimum, it was possible to raise the metered registration from 71.56 per cent in 1934 to 94.5 per cent in 1944. It is known from this experience that a goal of 92 per cent is not too high for most of us to maintain over an extended period. Having set that goal, the problem is to determine what the losses are and what means can be taken to correct them.

Unaccounted-for Water

"Unaccounted-for" water is water which is lost either through underground leakage, under-registration of meters or illegal hydrant use.

Before the percentage of unaccounted-for water can be determined it is first necessary to measure accurately the flow of water into the distribution system. A good meter is the most reliable means of measuring station output. If plunger displacement is resorted to, the slip of the pump should be accurately determined and checked from time to time.

At Kenosha there is a double check to determine station output. Both the low- and high-lift pumpages are measured through Venturi meters. Both the water used in the plant and that used for washing filters are also carefully metered. The total registration of the various plant meters is then deducted from the Venturi meter reading of low-lift pumpage. This adjusted total is then checked against the Venturi meter reading of the high-lift pumpage, or flow of water into the distribution system. The 1944 figures checked within 0.03 per cent, thereby indicating that the two station meters were maintaining comparable accuracies and that the measurement of flow into the distribution system was accurate.

The next step in determining the unaccounted-for water is to estimate closely the unmetered hydrant use. At Kenosha water used in flushing dead ends is determined by computing the hydrant flow, using the formula $Q = CAV$. The coefficient C is taken as 0.90; A is the cross-sectional area of the hose nozzle; and V is the velocity of flow computed from the pressure gage reading which is taken on the other hydrant nozzle while the hydrant is flowing. Water used in the Elgin sweepers is computed from tallies kept by the sweeper operators, and water used in flushing sewers, flooding neighborhood skating ponds and fighting fires is computed from the recorded time, size and length of hose, size of nozzle tip and hydrant pressure.

The fire and street departments are the only two agencies permitted to use the fire hydrants. Anyone else desiring to use a hydrant must first secure permission from the water department. When such permission is granted, the hydrant is either metered or the flow is computed from records that the user is required to keep. During the ten years that this system of hydrant control has been in effect the use of water through hydrants has ranged from 0.3 per cent to 0.8 per cent, indicating that the 15 per cent that our forebears allowed themselves was more than generous.

By adding the accounted-for hydrant use to the total registration on customers' meters and deducting this from the station output the amount of unaccounted-for water is determined. The question that now arises is: How much of this is underground leakage and how much is due to under-registration of customers' meters?

Underground Leakage

The permissible underground leakage allowance is an extremely controversial subject and there are as many answers as there are engineers. It is a well-known fact that the physical properties of the materials of construction preclude the possibility of building a bottle-tight system. By computing the expansion in one mile of cast-iron pipe using the summer-to-winter differential in water temperatures at Kenosha, it was found that if the pipe were free to do so, it would move 1⅓ ft. While it is true that most of this expansive force is dissipated in internally stressing the pipe, some of the joints in that mile of pipe do slip and leakage does occur despite all precaution. General practice, on new work, appears to justify a leakage of 60 to 250 gpd. per mile per inch diameter of pipe. (Even this lower figure is somewhat higher than that found by the Cast Iron Pipe Research Association, which, after conducting leakage tests in 25 cities in six states, found that the average leakage per mile of pipe, per inch of diameter, per 24 hours was only 41 gal.)

The pitometer engineers, who have a tremendous background of experience in making water waste surveys, set 3,000 gpd. per mile of main as the permissible leakage in old distribution systems similar to the one at Kenosha. This figure not only takes into account the leakage of mains, valves and hydrants, but the leakage of services as well. They contend that it is not economically feasible to locate and attempt to eliminate leakage less than this. If these criteria were applied to Kenosha's system, the permissible leakage would be 375,000 gpd., which, under normal peacetime operations, represents 7.5 per cent of the daily pumpage. Based on the wartime output, it represents only 3.75 per cent of the daily pumpage. From this determination it is readily seen that underground leakage is not a very large part of the unaccounted-for water.

Water Waste Surveys

A utility showing a high percentage of unaccounted-for water will find it sound economy to employ one of the engineering organizations, qualified by training and experience to make water waste surveys, to make a complete and comprehensive survey for them. The contract is usually made on the basis of one year's saving in wasted water, and usually provides that, should the money value of the wasted water disclosed by this survey exceed a certain predetermined maximum, only the

agreed maximum is paid. On this basis the utility is really undertaking a self-liquidating venture, since the entire payment cannot exceed the first year's savings.

Briefly, the first phase of the survey consists essentially of determining the exact amount of water being pumped into the distribution system. The next step is to subdivide the territory comprising the water distribution system into districts and to record the day and night flow into each district. Such a test is continued over a period of several days. The recorded consumption is then compared with the probable consumption calculated from the requirements of the district. If the flow into the district compares favorably with the calculated consumption, and if the flow during the night is not excessive, further investigation of that particular district is unnecessary. Should the consumption be excessive, however, the district is subdivided still further. Each portion is isolated and the rate of flow measured until the location of the abnormal consumption is approximately discovered. Further isolation of the exact source of leakage is made by means of a house-to-house inspection with the use of geophones and such other means as the experience and judgment of the engineer indicate.

The work of subdividing and investigating a district is usually done between midnight and 4 A.M., when both the consumption and the street traffic are at a minimum.

In addition to this district check up, all metered services 4 in. and larger are checked for under-registration of meters.

Such a survey was made for Kenosha in 1938. The survey disclosed that the city was losing 136,000 gpd. due to underground leakage and 209,100 gpd. due to under-registration of industrial meters.

The underground leaks consisted of two blown joints, one blown gasket in a flanged joint, one abandoned service and nine broken services. The annual saving derived from the survey was estimated at $9,687. The value of the water lost through underground leakage was figured at 6¢ per 1,000 gal. and amounted to $2,978. The value of water lost through under-registration of meters was based on the regular meter rates and amounted to $6,709.

Actually the loss due to underground leakage was only equivalent to the cost of the coal, power and chemicals required to treat and pump this wasted water. The loss due to the under-registration of meters, however, represented a very tangible loss in revenue.

In small systems, the superintendent can make a very satisfactory survey on his own by following the foregoing general procedure. Instead of using a Pitot tube, a good water meter installed on a hose line between two hydrants on opposite sides of a valve can be used to measure the flow into the district. By closing the valve and opening the hydrants the supply of water to the valved-off section passes through the meter.

The installation of test-tees or 2-in. corporations on the discharge side of all large industrial and institutional meters will provide the means for testing these meters. An accurately calibrated 2-in. disc meter can then be taken directly into the field and accuracy tests run on these large meters while in place on the customers' premises.

Under-Registration of Meters

Under-registration of meters is the real revenue thief. With thousands of

meters in a system the first question that comes to mind is: Which shall we check first? Experience at Kenosha indicates that the checking of the large industrial meters pays the highest dividends for the least effort. It was found that 37 per cent of the water sold, under normal peacetime conditions, is sold to industry. This water is sold through 75 meters or 0.7 per cent of the total meter installations. By promptly checking the accuracy of these large meters and by making the changes that such an accuracy test indicates, it is possible to meter accurately 37 per cent of the entire output. Some very startling discoveries were made while running accuracy tests on 75 large meters. Four were found to be from 71 to 86 per cent slow; three from 41 to 51 per cent slow; nine from 15 to 35 per cent slow and eight 12 per cent slow. In defense of the meter division it should be noted that, until the time the Pitot tests were made, there was little opportunity to check the accuracies of these meters, as there were no test-tees on the discharge side of the meters. The very best the men could do was to disassemble and clean the meters and see that they ran.

Needless to say, this situation was corrected promptly. The very old compound meters were replaced with batteries of 2-in. disc meters. Both battery and compound installations are in use at Kenosha and it is felt that each has a very definite role to play but the battery installations are strongly favored.

The 2-in. disc meter of today has very high accuracies at low rates of flow and has proved a real "revenue getter." Perhaps the greatest advantage of the battery installation is the facility with which individual meters can be removed from the customers'

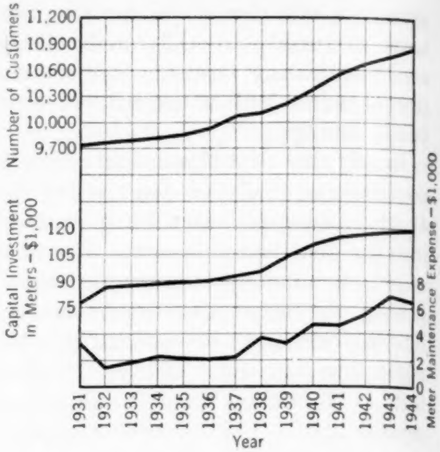


FIG. 3. Chart Showing Number of Customers, Capital Investment in Meters and Meter Maintenance Expense

premises and taken to the department's meter shop for test, inspection and repair. Moreover, this removal can be made without disrupting the customers' service. Having discovered that many of these large services were overmetered, it was found that a battery installation permitted great flexibility in changing meter capacities as required. Incidentally, a strip chart recorder is an invaluable aid in determining proper meter sizes.

After securing the maximum overall efficiencies on industrial meters attention was turned to the smaller residential and commercial meters. This job requires considerably more time and effort, since it is necessary to go over 99.3 per cent of all meters in the system. Since only 63 per cent of the plant output is sold through these meters the results are less spectacular in the over-all picture, but are none the less important.

Recognizing that each utility has problems which are peculiar to itself, it is not practicable to outline any specific

procedure that will be adaptable to all systems.

At Kenosha, in order to achieve results quickly, there was instituted an obsolescence program which provided for the replacement of meters by type and age groups. All meters over 35 years of age were replaced first, next all those over 30 years, etc. The program was interrupted during the war period because of meter shortages, but will be resumed as soon as meters are readily available.

Time did not permit the testing of all the meters as they were removed. Running accuracy tests on approximately every fifth meter removed indicated the wisdom of the obsolescence program. Only a few ran at 0.25 gpm. and many of them were extremely slow at the 1-gpm. rate.

These meters were replaced with meters of contemporary design capable of very high accuracies at low rates of flow. The specifications call for an accuracy of 97 per cent at 0.25 gpm. and 90 per cent at 0.125 gpm. It is appropriate here to mention the magnificent job done by the meter manufacturers. At a time when the A.W. W.A. meter specifications were holding the umbrella over a lot of weak sisters, the more aggressive meter manufacturers designed and engineered a meter far superior to anything that the trade was then demanding. They certainly deserve great praise.

A recent test of 25 new meters revealed that the average accuracy at 0.25 gpm. was 97.95 per cent and at 0.125 gpm. was 95.29 per cent. The over-all weighted average accuracy was 100.76 per cent. This latter figure was computed by taking the percentage of water used at the various rates of flow in normal residential use and the corresponding meter accuracies at those rates of flow. We don't dare tell our customers this, but water works men know that the customer isn't exploited for very long. After the meter has begun to wear and there is a consequent drop in accuracy the customer soon begins to gain.

After the "junkers" have been removed from the system, it becomes absolutely essential to institute a systematic and regular testing and repair program. The present cycle of periodic inspection is based on a ten-year frequency. This time schedule may have to be altered from time to time as experience and judgment dictate. A utility handling a ground water supply, where lime deposits in the measuring chamber become a problem, must of necessity conduct more frequent tests.

Results

Prior to 1931 the water consumers of Kenosha owned their own meters. At that time the utility purchased all of the meters then in service from the consumers at their depreciated value. Many of these were then ready for the scrap heap. Since taking over all meters, the water department has scrapped a total of 2,165, or 20 per cent, of all of the meters in service. The book value of these scrapped meters was $10,003.65. The obsolescence program was begun in 1937 and was cut short in 1941 because of wartime restrictions. The benefits derived from the obsolescence program can best be illustrated by noting the percentage increase in the quantity of water actually recorded on customers meters. This figure has risen from 69.3 per cent in 1931 to 94.5 per cent in 1944.

In making a further spot check on the value of these meter changes, 221

of these accounts were taken at random and a comparison was made between the average annual consumptions for the three years preceding the change and three years after the change and the average increase in registration was found to be 1,530 cu.ft. per year per meter. This spot check, however, does not mean much because of the many variables to be considered, but it does indicate a trend.

Probably the most significant measure of the value of these meter changes is shown in a comparison between the 1934 and 1941 records. In 1934 there was pumped to the distribution system exactly the same volume of water (within 0.01 per cent) as in 1941 (the last full year under normal peacetime operations), but in 1941 the metered sales amounted to $22,747.73 more than in 1934. That one year's saving alone was more than double the value of the meters scrapped and about 80 per cent of the value of all the new meters purchased.

Additional Federal Funds for Planning

Attention is invited to the availability of additional federal funds for loans to assist communities in planning postwar public construction.

An additional $12,500,000 was appropriated by Congress in December 1945 for the preparation of public works plans. The funds will be administered through the Bureau of Community Facilities of the Federal Works Agency. Applications for funds shall be made to the Division Offices of the Bureau of Community Facilities.

The advances need not be repaid until the construction of the public work is undertaken or started. A partial advance is made when the agreement is approved. The application must contain evidence that construction can reasonably be expected to start within four years and that it can be completed. Practically all types of public works may be planned by money from this appropriation except public housing projects, federal projects, and federal aid and state highway projects.

If any help is needed, consult the nearest Regional Office of the Bureau of Community Facilities or the Washington Office of the Bureau of Community Facilities.

Putting a Small Filter Plant Back on Its Feet

By R. B. Parsons

Supt., Water Works, Ripley, W.Va.

Presented on Nov. 16, 1945, at the West Virginia Section Meeting, Wheeling, W.Va.

THE municipally owned water system at Ripley, W.Va., furnishes water service to a population of 2,000 through 352 metered service connections. The system was installed in 1914 to furnish untreated water, but in 1935 the system was modernized and a 150-gpm. filtration plant was installed.

The water supply is pumped from Mill Creek, a fairly clean stream draining agricultural land. The stream is "flashy" and turbidity is high much of the time. The raw water is pumped by duplicate 150-gpm. centrifugal pumps and then discharged into an over- and under-baffled mixing chamber. Alum, and lime when needed, is applied on the suction side of the raw water pump. Following coagulation, the water is settled in a 44,700-gal. settling basin and then filtered through a 7 × 10-ft. rapid sand gravity filter. Filtered water is stored in a clear well beneath the filter and pumped from there into the system at a rate of 150 gpm. by duplicate centrifugal pumps. Chlorine and lime are applied to the filtered water in the clear well. The 150,000-gal. storage reservoir is located on a hill about one mile from the plant and floats on the system. This provides a pressure of 96 psi. in the business district.

In August 1943, when the author was hired by the city of Ripley as Superintendent of Water Works, the system was, in general, very run down, and the plant apparently had had no replacements and very little maintenance during the eight years of operation.

A financial statement received from the city water commissioner showed that the monthly running expense was approximately $560. This included salaries, extra labor, gas, electricity, chemicals, supplies, miscellaneous expense, printing, bonds, interest, etc.—extra labor other than the superintendent's salary was figured at $50 per month. These items would have to be paid for, of course, before any money was allocated for the repair of the plant and distribution system. The promised payments on outstanding accounts amounted to $295 and the over-all outstanding debts to approximately $5,000.

The monthly rates in effect at that time were:

Minimum charges (meter rent plus 2,000 gal.)	$ 1.20
Next 9,000 gal. (per 1,000 gal.)	0.45
Next 6,000 gal. (per 1,000 gal.)	0.30
Next 673,000 gal. (per 1,000 gal.)	0.20
Over 743,000 gal. (per 1,000 gal.)	0.15
MONTHLY INCOME (approx.)	600.00

An immediate attempt was made to raise the minimum charge to $1.75 but it was not until July 1945 that we succeeded in establishing a $1.50 rate.

An examination of the records showed that we were collecting for approximately 30,000 gpd. of water in

the period from April 1 to September 30. The pumps were being operated on an average of fifteen hours daily, seven days a week. This was necessary for the following reasons:

1. One high-service pump was pumping only 4,500 gph., just 50 per cent of its rated capacity.

2. The other high-service pump was completely out of working order.

3. The two raw water pumps were so badly worn they had to be used in unison to keep up with the high-service pump even at the low pumping rate.

4. The check valve on the extreme lower end of the suction line was worn out.

5. The clear well gage was not threaded up and had not been used for some time.

6. The loss-of-head gage was not threaded up and had been out of order for almost a year.

7. The lime feeder was not in use. Lime was added by the "bucket and scoop" method.

8. There was no float valve on the alum mixing chamber.

9. The compensator unit on the chlorinator was dead and the chlorinator was being operated by a bypass line.

10. There was no heater on the chlorinator, thus allowing the line to clog up daily.

11. The settling basin was approximately half full of sludge.

12. The reservoir was badly in need of cleaning.

13. New fencing around the reservoir was needed.

14. Dead-end lines, of which there are six, were badly in need of flushing.

15. The clear well was badly sludged up with lime.

16. There were approximately ten leaks in the mains and service lines.

17. The condition of the filter was such that it was necessary to backwash it every eight or ten hours to permit the flow of enough water to furnish the high-service pump. Filter sand flowed through the underdrain and clogged valves, lines and chlorinator.

Measures were taken to correct the foregoing conditions as well as others too numerous to mention here. Because nearly half of every day was spent in keeping the suction pump primed and running, the first step was the installation of a new check valve at the intake. The old valve was the flapper type, made of leather. It was replaced with a brass-faced flapper type, which has proved entirely successful except when a small stick or gravel lodges in it.

The next steps were to clean and disinfect the settling basin, repair the clear well depth gage and the loss-of-head gage; repair all leaks in the main line system and in service lines. The compensator unit of the chlorinator was sent to the factory for rebuilding and was then replaced. The reservoir was cleaned out, disinfected and refenced. All dead-end lines were flushed out every two weeks for about a year. (They are now flushed every 60 days.) One high-service pump was sent to the factory for rebuilding. The repairs included a new shaft and bearings, the turning down of impeller shoulders and the installation of new case-wearing rings. New case-wearing rings and new shafts were ordered for all other pumps and were turned down in the plant. In some cases it was necessary to build up the impeller shoulders with a bronze acetylene torch and then turn them down on a lathe.

Because of the difficulty of obtaining labor at the wages the city could afford

to pay and because of the lack of storage space (there was enough for only a two-day supply in the summer months), the filter repair operations were not undertaken until November 1944.

All available information on this type of filter was collected before starting construction. With 2 × 4-ft. timber and wire mesh the following screens were built:

Two 2 × 4-ft. screens of $\frac{1}{8}$-in. mesh wire.

One 2 × 4-ft. screen of $\frac{1}{4}$-in. mesh wire.

One 2 × 4-ft. screen of $\frac{3}{4}$-in. mesh wire.

One 2 × 4-ft. screen of 1-in. mesh wire.

One 2 × 4-ft. screen of $\frac{1}{8}$-in. rods (crossed) to make a 2-in. screen.

A place to screen the sand and gravel was prepared by building five bins outside the plant. This consisted of five different forms about 1 ft. deep and 10 ft. square.

The author, with the assistance of three men, removed the sand and gravel and placed it in prepared bins. One man shoveled the sand into the wash water troughs; one man shoveled it into a wheelbarrow, and one hauled it out and dumped it into the prepared bins. It was found that a considerable amount of the $\frac{1}{8}$-in. gravel had worked up into the sand, but all the larger gravel was packed pretty tight on the bottom around the laterals. The laterals, which are made of cast iron, had one 12-in. manifold through the center about 2 in. off the bottom, with a small air relief valve on top near the dead end which was completely stopped up. On each side of the main line of the manifold are ten 4-in. cast-iron laterals, about $2\frac{1}{2}$ ft. long, that extend to within 2 in. of the walls, making twenty in all. Before this job was started, all persons consulted expressed doubt that the laterals would unthread from the main part of the manifold because of the length of time they had been in, but they came out very easily with the use of chain tongs.

These 4-in. laterals have ten holes each in the bottom sides (drilled at an angle) about the size of a lead pencil and are lined with brass bushings. The holes were found partially stopped up with sludge and small gravel. Most of the laterals were full of sludge and gravel and sand, which was cleaned out by working it loose with a spud and washing out with water hose. The manifold was not removed but was cleaned out through the openings left when the short 4-in. laterals were removed.

The large gravel was graded first. It was placed in the drain trough and washed with a hose. This 3-in. layer of 2-in. and larger gravel came up far enough to cover the small holes in the laterals. Next, the gravel retained on the 1-in. screen was graded, and so on until all the gravel, except the $\frac{1}{8}$-in., was used. The 6-in. layer of $\frac{1}{8}$-in. gravel was mixed with the sand so thoroughly that it was not replaced until all the sand had been screened.

All the gravel, other than the $\frac{1}{8}$-in., measured out all right, but we were short about 1 in. of $\frac{1}{8}$-in. gravel and approximately 4 in. of sand. The sand was replaced, but not the gravel. The filters now operate satisfactorily; runs from sixteen to thirty hours are obtained between each backwash at the designed capacity of the plant and there is no sand feeding into the system.

It took four men three fifteen-hour days to complete the job, that is, 180 manhours. The author was fortunate in obtaining the services of exceptionally able men and everything went as

planned. A good policy would be to have at least six men to do the work in 45 hours.

After this work had been completed, it was learned that the former superintendent had removed all the sand and washed it, then stirred the gravel and tried to wash it with the hose while it was still in and around the manifold. This explains why the gravel was all out of place and why the sand was working down through the laterals. It proved a very costly mistake and did more harm than good. In the author's opinion it is never necessary to move the sand if the filters are properly backwashed, but we have found that a four-minute backwash is not quite half enough for the kind of water we filter at Ripley, which is very muddy. In order to keep filters from cracking and free from mud balls, it is necessary to backwash ten or twelve minutes every sixteen to thirty hours, depending on the condition of the stream.

The following tabulation shows the results of the work so far. It is planned to make several additional improvements when the funds become available.

	Before Reconditioning	*After Reconditioning*
Plant capacity, *gph.*	4,500	8,000
Period of Operation, *hr./wk.*	100	50
Cost of Power, *per mo.*	$140	$100
Average monthly expense	$559	$481
Amount of water sold, *gpd.*	30,000	55,000
Revenue from water sales	$600	$753

Water Supply Problems in Alberta, Canada

By D. B. Menzies

Provincial San. Engr., Edmonton, Alta., Can.

A contribution to the Journal

THE province of Alberta is located in the western portion of the Dominion of Canada, bounded on the west by the Rocky Mountains, on the south by the state of Montana and on the east by the province of Saskatchewan. It extends north from the International Boundary a distance of 756 miles and its area is 255,285 square miles. By far the larger part of the population is located in the southern half of the province.

The province has a population of approximately 800,000, of which approximately 100,000 persons reside in the city of Edmonton, 90,000 in the city of Calgary, 17,000 in the city of Lethbridge and 11,000 in the city of Medicine Hat. An additional 90,000 persons reside in small cities, towns and villages with populations greater than 300. Thus it is apparent that about 37 per cent of the province's population reside in cities, towns and villages, while the remaining 63 per cent live in small hamlets or on farms.

The province has four major physical divisions, namely, mountains, foothills, plains, and a small Precambrian area which occurs in the extreme northeast corner of the province. Eighty-seven per cent of the province's total area of 255,285 square miles lies in the plains division and the province is largely of a plains or prairie nature.

That portion of the province in which the largest proportion of the population is to be found is located on one of four major geological formations, namely, the Paskapoo formation, the Edmonton formation, the Bearpaw formation and the Belly River formation, named in the order in which each overlies the other. A geological map of the province is provided in Fig. 1. The Paskapoo formation, which varies in thickness from 1,200 to 2,000 ft., consists chiefly of soft grey clayey sandstones and clay shales of fresh water deposition. Many of these sandstones have relatively little thickness, and while some are aquifers, nevertheless the amount of water that can be obtained therefrom is very definitely limited. Typical analyses of waters obtained from the various formations are given in Table 1. The Edmonton formation, which immediately underlies the Paskapoo, consists of non-marine sandstones and shales interspersed with as many as fourteen different coal seams in certain parts of the province. Many of the sandstones of the Edmonton formation are water bearing, but, as in the case of the Paskapoo, the quantity available is limited. The sandstones in the Edmonton formation have a high calcium content and most waters obtained therefrom are very hard. Notwithstanding this fact, a number of zero hardness waters are also obtained from this formation. Many of the waters from both the Paskapoo formation and the

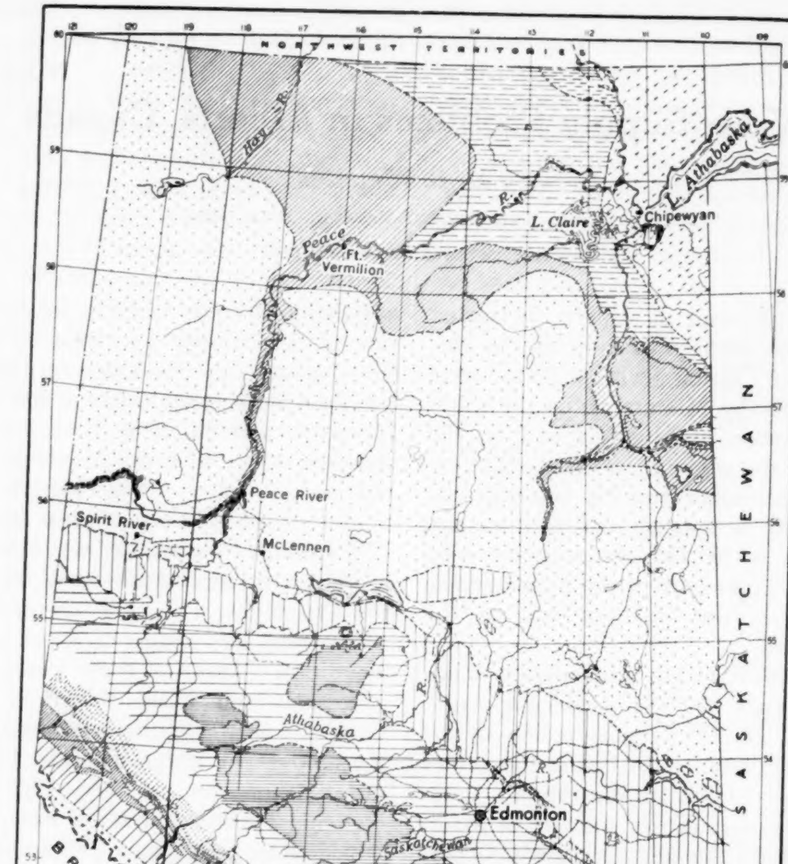


FIG. 1. Map of Alberta, Showing Four Major Geological Formations

TABLE 1

Partial Analyses of Alberta Well Waters Obtained From Different Geological Formations

Location of Well	Olds	Nanton	Edmonton	Gleichen	Holden	Barons	Vegrebille	Wainwright
Formation	Paskapoo	Paskapoo	Edmonton	Edmonton	Bearpaw	Bearpaw	Belly River	Belly River
Total Solids, *ppm.*	981	538	1,326	2,056	3,040	5,172	1,284	546
Loss on Ignition, *ppm.*	30	60	240	45	42	294	150	236
SO_4, *ppm.*	104	39	964	842	0	2,856	440	0
Cl, *ppm.*	63	52	4	31	1,682	51	13	3
Fe, *ppm.*	0.1	4.5	trace	—	trace	—	1.5	1.0
Carbonate Hardness, *ppm.*	0	0	490	48	90	480	200	430
Non-carbonate Hardness, *ppm.*	0	0	0	0	0	0	0	0
Alkalinity (Ph.), *ppm.*	0	0	0	0	0	0	0	0
Alkalinity (M.O.), *ppm.*	645	305	580	486	208	765	510	490
pH	8.0	8.4	—	7.3	7.8	—	7.5	—

Edmonton formation contain considerable quantities of dissolved gases, chiefly carbon dioxide, methane and hydrogen sulfide. Carbonaceous shales and seams of coal in many cases produce waters containing considerable organic matter and color.

The Bearpaw formation, varying in thickness up to 600 ft., underlies the Edmonton formation and outcrops in the easterly portion of the province. It consists mainly of grey brown and green shales containing a few bands of ironstone nodules and bentonite clays. These shales are almost entirely free from lime and such waters as are encountered in the formation usually show considerable quantities of sodium sulfate and sodium chloride, the Bearpaw shales being of marine origin. Such waters are obviously of no use from a water works standpoint at the present time. The Belly River formation, varying in depth from 1,400 to 5,000 ft., underlies the Bearpaw and consists chiefly of grey, greenish and buff sandstones interstratified with grey, greenish and carboniferous shales. Limited quantities of water, sometimes highly colored and mineralized, are obtained from this formation.

The analyses recorded in Table 1 show waters that will not in many cases meet the requirements of the U.S.P.H.S. Drinking Water Standards, and yet the farm people of the province use such waters with no apparent detrimental effect to their health.

There are many locations in the province, however, where either no water at all is obtainable or it is so highly mineralized as to be unusable for household purposes. Fortunately a large number of such rural areas are located on land served by irrigation, in which case water is obtained directly from the ditches during the summer and is stored in underground reservoirs during the winter months. Where there is no irrigation, farm water supplies are obtained by storing and melting ice, which is often obtained from many miles away, or else from artificially constructed ground storage reservoirs which receive an annual filling at the time the spring runoff takes place.

Wells as a Source of Municipal Supply

Of the 36 municipal water distribution systems in the province, only fourteen obtain their water supplies from ground sources. One of the fourteen is at present making a change-over from wells to a surface supply while another is considering a similar step. These systems supply a total population of only approximately 22,000 persons, whereas a population of approximately 250,000 is served from surface supplies. With two exceptions all the wells of the municipalities concerned are 100 ft. or more in depth and draw their water from one of the formations above described.

The problems associated with the development of wells for municipal water supplies in Alberta are many. As previously pointed out, almost all the drilled wells in the province obtain their supplies from narrow sandstone and shale strata. It is rare that such wells can be pumped at rates exceeding 20 gpm. when they are new, or at lesser rates when they get older, without excessive drawdown. This statement holds with respect to several gravel-walled wells in the province as well as ordinary drilled wells. It has also been the experience in most places that the water table progressively lowers with time and, even though additional wells have been constructed over fairly large areas, many towns are experiencing difficulty in getting sufficient water.

Part of the trouble in developing ground waters in the province no doubt results from the fact that there are relatively few well drillers who have sufficient experience to log a well properly. Provincial legislation does not require well drillers to hold any license, nor are they required to record properly the structures through which they drill. As a result the whole well drilling situation is not particularly good. There is every reason to believe that many inexperienced well drillers unknowingly go right through a water-bearing formation without knowing they are doing so.

The fact that most of the well waters are so highly mineralized also complicates the picture. Many hard waters, if softened with household softeners, immediately show excessive amounts of sulfate in the finished water. The excessive hardnesses likewise necessitate the installation of relatively large and costly softeners. There would appear to be a real field for the use of both cation and anion exchangers as a means of treatment, if the cost of the latter could be reduced considerably from prices at present being quoted. Table 2 shows partial analyses of the well waters in this region.

Surface Water as a Source of Municipal Supply

The province of Alberta is drained by two major drainage schemes. The

TABLE 2

Partial Analyses of Well Waters Used for Municipal Purposes in Alberta, Canada

Municipality	Population	Total Solids *ppm.*	Loss on Ignition *ppm.*	Total Hardness as $CaCO_3$ *ppm.*	SO_4 *ppm.*	Cl *ppm.*	Fe and Mn *ppm.*	Total Alkalinity *ppm.*	Trouble Encountered as Result of Water Quality
Camrose	2,600	1,120	78	0	124	48	—	700	
Coronation	580	1,080	68	10	220	13	0.1	570	Taste and color
Drumheller	2,748	470	164	360	79	12	3.5	275	Taste and odor due to iron and manganese
Edson	1,500	588	5	87	62	0	0	470	Good water
Gleichen	435	2,056	45	48	842	31	—	486	Taste; laxative, particularly to strangers
Grande Prairie	1,724	1,280	132	0	trace	17	—	1,040	Taste; water darkens cooked vegetables; poor for tea and coffee; foaming in boilers
Hanna	1,622	1,882	142	82	333	20	—	1,042	Water very corrosive, chiefly on meters; taste.
High River	1,430	314	26	262	63	trace	—	200	Good water
Lacombe	1,603	584	40	0	0	17	0.3	485	
Lloydminster	1,622	1,452	214	400	45	71	0.1	435	Excessive hardness
Magrath	1,207	1,622	18	458	805	10	—	430	Excessive hardness
Stettler	1,295	964	86	0	90	8	—	665	Taste; discoloration of cooked vegetables
Vegreville	1,696	1,284	150	200	440	13	1.5	510	Taste; high iron content; aeration aggravates corrosion
Wetaskiwin	2,318	783	7	0	53	109	0.3	470	H_2S in some wells; aeration aggravates corrosion; color

southern and central portion of the province is drained by the Saskatchewan River system, which flows in a generally easterly direction and finally empties into Lake Winnipeg; and the northern portion of the province is drained by the Mackenzie River system, which eventually empties into the Arctic Ocean. Both systems have their sources in the Rocky Mountains. The various rivers comprising both systems have relatively high velocities as compared with some of the rivers in the central and eastern part of the con-

tinent, and as a result are often highly turbid during the longer part of the summer season.

By the time the snow waters from the mountains reach the foothills they have usually taken on some hardness. The water supply at Banff shows 200 ppm. total solids and a hardness of 180 ppm. as $CaCO_3$, that at Mercoal 148 ppm. total solids and a hardness of 120 ppm., and that at Pincher Creek 236 ppm. total solids and a hardness of 205 ppm. The hardnesses obviously fluctuate as between the summer and winter seasons. The above towns are all located in the mountains or in the foothills.

Upon leaving the foothills the two major drainage systems break out onto the plains, a part having heavy tree growth and vegetation, and the remaining portion being of a prairie nature. At the time of the spring runoff, water from the plains is usually highly colored and high in turbidity, thus throwing a considerable load on filtration plants concerned. Hardness, however, does not increase greatly during the summer season as compared with the mountain waters, but does go up to as high as 350 ppm. as $CaCO_3$ during the fall and winter. There are two municipalities in the province which depend on small streams of local origin for their supply of water. Two other municipalities are at present considering similar installations. All the streams concerned have very limited flows and are often dry for regular intervals, with the result that the impounding reservoirs concerned become somewhat stagnant, develop offensive tastes and odors, become very highly mineralized and develop considerable color. One such reservoir, which, during the late spring immediately following the runoff, showed a total solids of 516 ppm., a hardness of 182 ppm. and a sulfate content of 70 ppm., had by the following late winter increased to 1,436 ppm. total solids, 504 ppm. hardness and 508 ppm. sulfates.

Color removal from surface waters likewise presents an expensive problem. In the first place the cost of filter alum in the province, due to high freight rates, is between 3¢ and 4¢ a pound when bought in carload lots. Lime and soda ash are correspondingly high. The alkalinity of most surface waters in the province seldom goes to below 200 ppm., so that pH adjustment to produce a color floc usually requires an alum dosage in the order of 170 ppm. The substitution of mineral acid for alum has been done experimentally, but fear of adverse public opinion has prevented its adoption.

Taste and odor control presents the same problems as are being encountered in other parts of the continent and so do not need elaboration in this paper.

Softening of a municipal water supply is being practiced in only one city in the province and there with good results and at a very reasonable cost. There is reason to believe that several other cities will commence softening operations in the near future.

Construction and Operational Problems

The fact that the province is located as it is in the western portion of the Dominion means that, due to high freight rates, pipe and other equipment cost as much as, and usually more than, in other parts of the continent. Winter temperatures as low as — 50°F. make it essential that water mains be laid on the average with at least 7 ft. of cover, some gravelly soils needing as much as 12 ft. if the freezing of pipe is to be prevented. Ditching and labor costs in

the past would appear to have been lower than in many other parts of the continent, but the trend at the present time is definitely upwards. (Present Alberta tenders indicate that the cost of cast-iron water mains complete are about 135 per cent in excess of the prices quoted by Howson [Jour. A.W. W.A., **35**: 1521 (1943)] as applying to practice in the midwestern states for 4-in. pipe, and 115 per cent in excess for 12-in. mains.)

It is the exception to find inside pitting or tuberculation in metal pipes in Alberta except in hot water pipes. This is also true in the western states where waters of relatively high alkalinity predominate. On the other hand, galvanic action is very noticeable in many Alberta waters where metals of different kinds are brought into close contact. Waters high in the sodium salts produce relatively strong electrolytes, and the galvanic action produced is very rapid. Several towns operating vertical shaft turbine pumps, in which the impellers were made of bronze and the encasing bowls of cast iron, have found the efficiencies of the pumps to have dropped off so much due to galvanic corrosion of the cast iron that replacement of the bowls has had to be made in periods as short as seven years after the original installation.

While inside corrosion is extremely uncommon, that from the outside of the pipe is very rapid in many cases. It is particularly noticeable in areas containing soils derived from geological formations rich in the sodium salts. There are areas in the province where galvanized iron services have lasted only two to three years. There are other areas in the province where cast-iron pipe has been pitted so badly on the bottom side that failure has occurred within fifteen to twenty years following laying. Most of such pipe has been of the 150-lb. class, there being no evidence to show that similar failure has occurred in heavier pipe. No cathodic protection, to the author's knowledge, has ever been provided for water mains or for elevated tanks. A certain amount of such protection, using zinc anodes, has been provided for steel pipe conveying natural gas, with good results in some types of soil and poor in others. The use of direct current has not been tried to any extent, but experiments using this method are planned for the near future.

Summary

The main problems encountered in the province would appear to be the difficulty in getting water of good chemical quality in sufficient quantity from wells; the relatively high cost of pipe, chemicals and other material due to the westerly location of the province; hardness and the difficulty of removing color from surface waters; and external corrosion of metal pipes.

Training Plant Operators at Fort George G. Meade

By Albert M. Tawney

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Presented on Dec. 14, 1945, at the Four States Section Meeting, Baltimore, Md.

THE war created a serious shortage of skilled operators for water and sewage plants in military communities in the Fort Meade area. This was due to the greatly expanded facilities which required at least double the previously used operating personnel and, also, to the wholesale loss of trained men to the Armed Forces through the "Greetings" route. No exemptions were given because of military employment, it being ruled that a draft age man's first duty to his country was combat service, rather than policing water through a water or sewage plant. No one could get a man deferred because of civilian employment at Fort Meade, so we began to train older men processed through the Post Engineer and Civilian Personnel Office.

Training Program

The training of operators for the water and sewage plants at Fort Meade is not new. It has been in continuous operation since World War I. All classes of personnel have the opportunity for learning all phases of plant operation and maintenance. We are proud of the fact that John Jones, a pumping plant operator, could operate a shift at the filtration plant, and it is not unusual to see the filtration plant operator doing the work of the plant chemist, making necessary analyses—physical, chemical and bacteriological—of raw and purified water. This provides operating flexibility. It also permits the chief to get away to the excellent nearby race tracks every now and then, thus preserving sanity and observing one of the oldest Army rules: "Don't take yourself too damned seriously."

This peacetime training procedure proved advantageous when the manpower shortage hit. The post was tremendously enlarged with the construction of a new filtration plant, extension of the distribution system, a new sewerage system and a new sewage disposal plant to care for the needs of a post population of 40,000 to 50,000. The plant personnel was increased 100 per cent to meet wartime increases. The training of plant operators was increased, and, for a while, everything ran smoothly. Then came "Greetings" and we lost men faster than we could train them and were compelled to concentrate on the older men.

Major A. E. McCaskey, Corps of Engineers, Office of Chief Engineers, Washington, D.C., formerly Chief of Utilities, Repairs and Utilities Branch, Office of Service Command Engineers, Baltimore, Md., who before the war was Professor of Sanitary Engineering at the University of West Virginia, was a frequent visitor to the plant and became greatly interested in the training program. He arranged for it to be

expanded to include trainees from other posts and stations in the Third Service Command.

One particular military post was of such a secret nature that it required all military personnel for operations. Those operators were trained at Fort Meade.

The first men from other posts arrived for training in August 1943; and from August 1943 to September 1945, fifteen civilian and nineteen military personnel were trained in the operation of water and sewage plants, in addition to the 42 persons for the Fort Meade plant.

The training program was very short —21 days at each establishment. This was due to manpower shortage and to the necessity of getting the trainee on the job as soon as possible and with as much knowledge and practice as possible. *Standard Methods, Water Supply Control,* by Charles Cox, *Water Purification for Plant Operators,* by Norcom and Brown and *Water Purification and Principles of Sewage Treatment,* put out by the National Lime Association, Washington, D.C., were used as texts and reference books.

The course is of a practical nature. It consists of learning while actually working on the job with explanations of plant construction, operation, maintenance and the keeping of proper records.

There is no written or oral examination because competence in practice is one of the primary purposes of the training program. The trainee is required to keep a note book and to record in a daily diary a record of his work. This diary is checked daily by the instructor and the author. No corrections, other than proper nomenclature of plant appurtenances, are made. This diary is typed exactly as written and forwarded through channels with recommendations as to his aptitude and ability to his home station. By this method the man's proficiency is easily noted.

In collaboration with the Civilian Training Section, the program for training water and sewage workers was more efficiently carried out by the use of "on the job" instruction.

This "on the job" instruction consists of four steps:

Step 1—Prepare the Worker

a. Put him at ease.
b. Find out what he already knows about the job.
c. Get him interested in learning the job.
d. Place him in the correct position.

Step 2—Present the Operation

a. Tell, show, illustrate.
b. Stress key points.
c. Instruct clearly and completely, taking up one point at a time, but no more than he can master.

Step 3—Try-out Performance

a. Test him by having him perform job.
b. Have him tell and show you; have him explain key points.
c. Ask questions and correct errors.
d. Continue until you know he knows.

Step 4—Follow-up

a. Put him on his own.
b. Designate to whom he goes for help.
c. Check frequently; encourage questions.
d. Get him to look for key points as he progresses.
e. Taper off extra coaching and close follow-up, all of which simply boils down to man-to-man instruction.

TABLE 1

JOB BREAK-DOWN SHEET FOR TRAINING MAN ON NEW JOB

Part: Water Filtration Operator	*Operation: Water Purification*
Important Steps in the Operation *	Key Points †
1. Source of supply Area of watershed Characteristics of supply	a. Turbidity—stream flow
2. Raw water pumping Securing water for purification	a. Rate of pumpage from low lift b. Notify low-lift amount of water required c. Check rate of flow meter
3. Preparation and control of chemicals and chemical feed equipment	a. Charge chemical feeders b. Check pre- and post-chlorinators c. Check chemical feeders
4. Chemical tests—dosage Mixing, coagulation Sedimentation of water	a. Make necessary chemical tests b. Run alum dosage test c. Check mixing, coagulation, sedimentation
5. Operation of filters	a. Check condition of filter influent b. Check filter operation c. Check loss of head d. Check filter effluent
6. Sterilization and post treatment of filtered water	a. Check chlorine residual b. Check pH and lime
7. Control of water Pumping to distribution system	a. Check clear wells hourly b. Check pumping plants hourly; have pumping plant operators call in hourly to report plant operation.
8. Chemical and bacteriological analyses	a. Chemical analyses of raw and treated water b. Bacteriological analyses of raw and treated water c. Record analyses
9. Maintenance and minor repairs to plant and equipment	a. Check heating of motor bearing; grease and oil necessary equipment b. Make necessary minor repairs to plant and equipment
10. Plant records Supplies, requisitions, etc.	a. Record hourly all phases of plant operation: 1. Water treated, water distributed 2. Chemicals used, power consumption 3. Chemical and bacteriological analyses 4. Weather temperature, barometer readings 5. Daily record, plant log

* *Step:* A logical segment of the operation when something happens to *advance* the work.

† *Key Point:* Anything in a step that might make or break the job; injure the worker; or make the work easier to do, i.e., any knack, trick, special timing or bit of special information.

TABLE 2

TRAINING TIME TABLE

Water Works—1943–1945

	Water Purification, Pumping Supervision	Chemical and Bacteriological Laboratory Control	Requisition Supplies, Records and Reports	Operation of Filtration Plant	Operation of High-Lift Pumping Plant	Operation of Low-Lift Pumping Plant	Operation of Annapolis Hill Pumping Plant	Maintenance and Repair of All Plants	Chlorination, Distribution System Breaks, Repairs	Water Sampling Daily Taps on Distr. System
Engineer	√	√	√	√	√	√	√	√	√	√
Filtration Operator or Asst. Supt.	√	√	√	√	√	√	√	√	√	√
Chemist	√	√	√	√	√	√	√	√	√	√
Filtration Operator	√	√	√	√	√	√	√	√	√	√
Filtration Operator	√	√	√	√	√	√	√	√	√	√
Filtration Operator	√	√	√	√	√	√	√	√	√	√
Senior Operator, Mechanic			√	√	√	√	√	√	√	√
Pump Operator, H. L.		√	√	√	√	√	√	√		√
Pump Operator, H. L.		√	√	√	√	√	√			√
Pump Operator, H. L.		√	√	√	√	√	√	√		√
Pump Operator, H. L.		√	√	√	√	√	√	√	√	√
Pump Operator, L. L.					√	√	√	√		
Pump Operator, L. L.					√	√	√	√		
Pump Operator, L. L.					√	√	√	√		
Pump Operator, L. L.				√	√	√	√	√		
Pump Operator, A. H.					√	√	√	√		
Pump Operator, A. H.					√	√	√	√		
Pump Operator, A. H.					√	√	√	√		
Pump Operator, A. H.					√	√	√	√		
Senior Laborer								√	√	√
Chemist, Standing Operating Procedure		√	√	√	√					√

Note: Checks indicate completion of training. When using table insert dates in place of checkmarks.

Through the use of on the job instruction, the "job method" program was developed. This program is a practical plan designed to produce greater quantities of quality products in less time by making use of the manpower, machines and material available. The "job method" program is also broken down into four steps:

Step 1—Break Down the Job

a. List all details of the job exactly as done by present methods.
b. Be sure details include all material handling, machine work and hand work.

Step 2—Question Every Detail

a. Use these types of questions:
Why is it necessary?
What is its purpose?
Where should it be done?
When should it be done?
Who is best qualified to do it?
How is the best way to do it?
b. Question the trainee regarding materials, machines, equipment, tools, product design, layout, work place, *safety,* housekeeping

Step 3—Develop the New Method

a. *Eliminate* unnecessary details.
b. *Combine* details when practical.
c. *Rearrange* for better sequence.
d. *Simplify* all necessary details.
To make the work easier:
(1) Pre-position materials, supplies and equipment at the best places in the proper work area.
(2) Let both hands do useful work.
(3) Use devices for holding material.
e. Work out your idea with others.
f. Write up your proposed new methods.

Step 4—Apply the New Method

a. Sell your proposal to your "superior."
b. Sell the new method to the employees.
c. Get approvals from all concerned.
d. Put the new method to work. Use it until a better way is developed.
e. Give credit where credit is due.

The results of the application of the on the job training and the job methods training were a "job break-down sheet," shown in Table 1, and a "training time" table, Table 2. These clearly indicate important steps in the operation and key points. The time table indicates the training of personnel to fill all positions.

The co-operation of all concerned is essential for a successful training course. Team work has made this program at Fort Meade a success. The key men were taught to be instructors and, with the use of this program, the training time was cut in half by making use of inexperienced personnel, while at the same time 50 per cent more knowledge was imparted in the same period of training.

Checking the Distribution System

By Harry Breimeister

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Presented on Nov. 13, 1945, at the Wisconsin Section Meeting, Milwaukee, Wis.

IF water were delivered to consumers by truck, we would, undoubtedly, spare no effort or reasonable expense to develop a delivery system which would function with the greatest efficiency and economy. We would determine the shortest routes, the necessary truck capacities and the operation best suited to satisfy the variable demands of water consumers. If some of the trucks were traveling light while others were being overworked, we would rearrange the routes and equipment to permit more uniform usage. We would keep the trucks well serviced and repaired and check them frequently for mechanical defects. We would do all these things to promote better service to our customers, but, in so doing, we would also benefit ourselves operationally and financially. In other words, it would be good business.

However, a water distribution system, although essentially a delivery system, unfortunately has most of its facilities hidden from visual inspection by several feet of earth. Once installed, they are not readily accessible. Inadequacies are not as apparent, nor are they as readily corrected as are those in a system which functions before our eyes. As a result, many communities adopt an "out of sight, out of mind" policy toward that vital component of a water works system. We seem to forget about it until surface developments, such as leaks, poor pressures or complaints of inadequate service, bring the realization that it requires attention.

The repair of leaks is a fairly well-established routine which permits little deviation in the methods used. The leak must be exposed and repaired without much choice on your part. The correction of pressure and service deficiencies, however, is a matter which has no such obvious solution. It is true that the most common remedy is the installation of additional mains, and in extreme cases involving extensive areas, major facilities such as intakes and pumping stations may be constructed. These may not be the most efficient and economical measures, but if the desired improvement is obtained, the methods are seldom questioned.

This "hit-and-miss" method of developing a distribution system is not the practice in Milwaukee. The distribution system covers an area of 45 square miles and includes 1,000 miles of water mains. The water works supplies, in addition to the city of Milwaukee, five suburbs and the county institutions. With $20,000,000 invested in mains and hydrants, it is believed to be good economy to check their operation with the intent of using existing facilities to their best advantage, reinforcing them only when and where necessary. Inadequacies, when they develop, appear most often at the ex-

tremities of the system; consequently, corrective measures may be very expensive and not entirely efficient or effective if the way the system is functioning during periods of heavy consumption is not definitely known. For that reason the Research Division of the Milwaukee Water Works was established eighteen years ago, and through its annual pitometer and pressure surveys it has maintained an effective check on the operation of the system.

A discussion of critical flows and pressures is not complete without mention of the maximum consumption demands which create them. A water works system serves a dual purpose: first, to supply the normal domestic and industrial requirements and, second, to furnish water for fire protection service. Its design is governed largely by the maximum demands which it must supply. In small systems, these are usually established by the theoretical fire requirements. In large systems, however, the actual peak use is substantially greater than the maximum demand based on the National Board of Fire Underwriters' requirements. Milwaukee's maximum rate of use, as determined by the fire requirements, is 193 mgd., whereas the water works has experienced actual demands at rates as high as 300 mgd. In practically all communities, peak consumption conditions prevail for but a few hours on relatively few days of the year. This means that much of the system's capacity lies idle during the greater part of the time. The peak load is very expensive to supply and the income from the sale of water to satisfy it does not begin to cover the actual cost.

As much as two-thirds of the investment in the average water works plant is in the distribution system. It is surprising, therefore, that more attention is not paid to how effectively it is being utilized or how best to plan its development to meet increasing or changing demands. The growth and expansion of distribution systems parallel that of the communities which they serve; a pattern which is often erratic and unpredictable. Shifting industrial and domestic demands add further to the changes in amount and direction of flow, especially in gridiron systems having numerous cross-connections. Distribution system diagnosis through pitometer surveys is the only means of ascertaining with reasonable accuracy the changes which occur.

Milwaukee has 114 gaging stations, so located that it is possible to measure the flows in the feeder mains serving various areas in the city or the suburbs. More are being added as new mains are constructed. The primary concern is the determination of maximum flows. These obtain during the summer months and are occasioned by a combination of the domestic, industrial and lawn sprinkling loads. They occur in the early evening hours between 5:00 and 8:00 P.M., with maximum rate of use at approximately 7:00 P.M. The peak rate is three times the average, although in the high-service district, which includes two-thirds of the city's area, it has reached four times the average daily use.

The distribution system at Milwaukee functions differently under peak loads than it does under average consumption conditions. There are two reasons for this variance. First, the supply from the major pumping stations is supplemented by water introduced into the system from the storage

facilities. Secondly, the lawn sprinkling load, which is a major contributor to the peaks, is not uniform in different sections of the city. Thus, with additional sources of supply and a variable increase in demand because of the non-uniform sprinkling load, the flows in the system are substantially different. It is a common practice to determine maximum flows from the average flows by applying to the latter a multiplier equal to the ratio between the consumption on the peak and average days. It is obvious that such a method cannot be used where storage facilities are in operation for the peak periods only. In fact, pitometers record a complete reversal of flow in some of the mains when certain of the storage facilities are operating.

The instruments and personnel necessary to make a simultaneous pitometer survey of the entire system are not available; however, the water department is equipped to measure the flows in feeder mains supplying well-defined areas. There are eight recording instruments and eight pitot tubes of various lengths for different diameter pipe. Five of the recorders are of the mechanical type, two are photographic and one is electrical. Each is used in conjunction with a pitot tube with the exception of the electrical recorder which is attached directly to the meter and records the flow through it. This latter instrument is especially suited for measuring the rate of use by large customers.

The pitometer pits are enlarged manholes built directly over the main. A standard 1-in. corporation cock is tapped into the top of the main on its vertical axis and the pitot tube is inserted through this opening. A pitot tube is a comparatively simple instrument, consisting of a hollow shell enclosing two tubes which terminate in orifices. These are set on the centerline of flow in the main, with one orifice facing upstream and the other downstream. The pressure differential in the tubes resulting from the opposing position of the two orifices is transmitted through rubber tubing to the recorders and can be readily converted into flows through the application and use of formulas and tables. This is possible because there is a definite and known relation between the pressure differential and the rate of flow.

Since most mains are in the pavement area, recorders are kept out of the street by running a $2\frac{1}{2}$-in. conduit from the pitometer manhole to a point behind the curb and drawing the rubber connecting lines through it. Thus, there is no interference with either vehicular or pedestrian traffic.

In 1943, the Pitometer Company of New York was retained by the city to make a trunk line flow survey of the distribution system. In five months of field work, 24-hour flow measurements were obtained at 173 gaging points in groups of five or six simultaneously. The survey concluded that the feeder mains were in excellent condition and adequate for their present use. This failure to reveal inadequacies in the feeder system substantiates, in effect, the value of the annual pitometer work.

The flow surveys also proved of great value in water rate litigation before the State Public Service Commission and the courts, In determining the cost of service to the suburbs, their ratio of peak-to-average use was considered as an important cost factor. It was only by means of the pitometer surveys that it was possible to prove that the peak rate of use in the suburbs was relatively higher than in the

city and in one instance reached nine times the average as compared to a 3 to 1 ratio in the city.

The pitometer survey is an effective means of locating water waste, and in communities where the unaccounted-for water is relatively great, it may produce a substantial saving in the cost of operation. On occasion, when the pitometers have disclosed excessive night flows which could not be substantiated by the known use along the lines under consideration, a check was made for leakage or unauthorized use of water. Comprehensive water waste surveys have not been conducted in Milwaukee, however, because the unaccounted-for water in the system is comparatively small. Approximately 85 per cent of the total pumpage is paid for and a substantial portion of the remaining 15 per cent can be accounted for by under-registration of meters, flushing and filling of mains, settling of trenches and breaks in mains. The relatively small amount of undiscovered leakage does not warrant the expense of an elaborate leak survey, for in a system as extensive as Milwaukee's it is to be expected that some water will escape regardless of any measures against it.

By means of the annual pitometer surveys it is possible to determine which of the mains are functioning properly, those which are overloaded and those which are laggard and inefficient. It is often possible to increase the effectiveness of the same combination of mains by installing comparatively inexpensive cross-connections or valve arrangements. Accurate flow data are essential to the efficient design and operation of a water works system and for that reason the pitometer work is considered a valuable asset.

During the summer months also, a pressure survey is conducted. This is believed to be the most economical and efficient means of checking the adequacy of service furnished to consumers. Most consumer complaints are occasioned by poor pressures because of the inconveniences and discomforts they create. Poor pressures are probably more significant as an indication of an inadequate supply for fire protection service; however, regardless of the effect they produce, poor pressures are deficiencies which solicit a quick response from consumers.

Approximately 20 recording pressure gages are installed, chiefly on hydrants, at critical points in the distribution system. They are housed in specially-designed steel boxes which attach to the hydrant in such a way as not to interfere with its use by the fire department. The hydrants have a removable ¼-in. plug at the rear of the nozzle section. By removing this plug and inserting a hose connection from the gage, it is possible to obtain a continuous pressure record without using the hydrant nozzle. Pressure charts are changed daily and any abnormally high pressure losses are investigated immediately. From the pressure data thus obtained, tables have been compiled which show the static and minimum pressures at practically every street intersection in the city.

There are a few locations in the system where unsatisfactory pressures may prevail for a short time during periods of heavy consumption. In most instances, however, pressure deficiencies have been eliminated by the installation of storage facilities and feeder mains. Both of the major pumping stations are located in the northeast section of the city and, as a

consequence, water to reach the far south side of the city must travel a distance of sixteen miles. Prior to the installation of storage, the pressure at South 20th Street and West Morgan Avenue, the critical point in this area, regularly dropped to zero during periods of peak consumption, a pressure loss of 65 psi. By installing two 1.5-mil.gal. elevated tanks and a booster station with two 6-mil.gal. ground storage tanks this condition has been improved, so that today, despite a considerable increase in consumption, a 10-psi. minimum is maintained at that point under the most severe conditions.

There are several areas in the west and northwest sections of the city where pressure improvement is desirable but difficult to obtain because of high ground elevations. At the high point in this section, the maximum pressure possible with no allowance for loss due to friction is 27 psi. The installation of storage facilities has produced an improvement at this point, but it is obvious that with such a low pressure to begin with very little loss can be experienced without creating a condition of inadequacy.

The pressure survey is also of material assistance in locating water hammers in the system. On several occasions, industrial plants and schools have experienced damaging water hammer which they believe was transmitted through the system onto their premises. By spotting recording pressure gages on the premises and on hydrants in the vicinity, the hammer has been localized within a comparatively small area and the cause subsequently determined. In most instances, water hammer is created on the premises of the complainant by quick-closing or loose valves, pressure regulators or other appurtenances interfering with the smooth flow of water; however, without definite proof provided by the pressure charts, it is difficult to convince consumers that they themselves are quite often responsible for the water hammer.

An appreciable sum has been invested in pitometer and pressure equipment, and a workship where it is stored, repaired and tested has recently been completed. The money expended for carrying on pitometer and pressure surveys is, the department believes, well spent, and it has paid dividends in many ways—efficient design and operation, valuable data for water rate and service litigation and economy and savings in capital expenditures. The lack of accurate knowledge of the operation of the distribution system, especially during periods of peak consumption, may result in a considerable waste of money for unnecessary or ineffective improvements. It is believed, therefore, and the record bears it out, that flow and pressure surveys are desirable and essential in promoting efficiency and economy in the design and operation of a water works system.

Studies of the "Filto-Kleen" Device

By Harry E. Jordan

FOR some months, various department stores over the country have been offering for sale a filtering device called "Filto-Kleen." The attention of the author was called to publicity material which had been distributed by one of the large department stores in New York City. A member of the A.W.W.A. staff purchased two of the units and one was sent to each of two members of the Association who are in responsible charge of water examination laboratories. The author certifies that the test procedures were in accordance with good practice and that the technicians who made the examinations are competent. The names of the persons who made the examinations of performance of the faucet filters are held in confidence.

Before recording the results of the tests made, it is proper to refer to the publicity material which is distributed by the maker of the device. A leaflet which is handed to the customer when the purchase is made bears study. An exact reproduction (not in the striking red and black type of the original) of a portion of the leaflet appears herewith. The uninformed person will be frightened by the semi-human figures which are scattered across the page. The informed person knows that no such "organism" exists outside the imagination of the person who made the drawing.

The leaflet claims that the "Filto-Kleen":

1. Eliminates impurities 99.9 per cent
2. Fits any faucet
3. Prevents splash
4. Rust proof
5. Crack proof

The filter devices were placed on faucets which were under the control of the operators to whom the units were sent. Operator No. 1 used a regular kitchen tap for the supply of water and recorded bacterial counts (per ml.) and turbidity, both before and after passing water through the device. Operator No. 2 used a source of supply of water which contained a higher bacterial flora than normally distributed. Counts per milliliter were made before and after the water passed through the device.

Results tabulated by Operator No. 1 are shown in Table 1.

TABLE 1

	Kitchen Tap		Filto-Kleen Tap	
Date	*Bacterial Count*	*Turbidity*	*Bacterial Count*	*Turbidity*
Oct. 8	2	0.4	2	0.2
9	3	0.6	4	0.4
10	3	0.6	2	0.4
11	2	0.6	2	0.5
12	5	0.6	3	0.6
13	3	0.8	0	0.6
15	21	3.0	18	2.0
16	5	1.0	3	0.8
18	12	0.8	50	0.8
19	2	1.0	0	1.0
20	2	8.0*	3	1.0
21	2	9.0*	2	3.0
26	4	1.0	4	1.0
31	8	1.0	200	1.0
Nov. 9	1	1.0	4	0.5
13	2	1.0	5	0.5
20	2	0.8	3	0.5
27	1	0.8	4	0.5

* High turbidity due to flushing hydrant nearby.

Results tabulated by Operator No. 2 are given in Table 2.

TABLE 2

Date	Bacteria per ml. at 37°C. *Unfiltered*	Bacteria per ml. at 37°C. *Filtered*
Sept. 27	137	132
28	300	475
28	60	40
29	95	360
Oct. 1	43	320
2	30	46
4	26	95
6	180	107
7	110	173
9	22	22
10	475	50
12	450	170
14	14	200
15	3	2,700
16	2	3,200

Operator No. 2 made the following comments:

"The pad was on the faucet for twenty days, and in that time it increased in weight by 27 mg. Of this weight, 7.4 mg. were accounted for by scale which could be picked off, and which obviously came from the inside of the pipes, probably deposited there before softened water was used in the system. Considering the whole weight, the filter picked up 1.35 mg. per day. If we assume that the use of water amounted to 75 gpd., the solid matter picked up amounts to 0.0047 mg. per 1. While the iron stain is quite apparent on the pad, the solid matter it collects is rather inconsequential."

Returning to the claims made by the maker of the device:

1. "Eliminates impurities 99.9 per cent." The removal of bacteria is irregular. On the average of both tests, bacteria are added to the water which passes through the unit rather than removed from it. This is likely to be the case with any normal public water supply in the United States. The filter unit is a loose fibrous material which probably can act as a site of growth of the few harmless bacteria remaining in the city supply after it has been filtered and chlorinated. The most that can be said for the filter is that it does not appear to promote a consistently high growth of bacteria.

The device does not completely remove turbidity from a normal public supply. It does appear to reduce it somewhat, but the turbidity noted by Operator No. 1 is not of the magnitude which would be noted by the public.

2. "Fits any faucet." This appears to be true.

3. "Prevents splash." This appears to be reasonably true.

4. "Rust proof." The device is made of plastic materials and is not likely to rust.

5. "Crack proof." This is probably true within limits. Any plastic material can be broken if hit hard enough, but the device is not likely to be broken under ordinary conditions of use.

While the illustrations on the circular tend to make the innocent buyer think that his water supply is filled with frightful looking organisms, the text in the main is carefully phrased and probably of such nature that in trade proceedings would not be called *false* advertising. One sentence steps decidedly beyond the limits of truth:

> In actual laboratory tests, ordinary tap water has been found to contain large quantities of microscopic organisms—both living and dead—and particles of suspended vegetation not visible to the naked eye.

The simple fact is that "ordinary tap water" *does not* "contain large quantities of microscopic organisms."

There is no point to extending comment on this subject. The statement is incorrect.

The tests which have been made of the device show clearly that it has no striking ability to remove bacteria from water. Since the normal public water supply in the United States does not contain enough bacteria to make their removal a problem of any importance to the householders, the relative inability of the unit to remove bacteria is of minor consequence. The device does reduce splash and it looks pretty.

Jamaica, New York—Survival and Retirement Experience With Water Works Facilities

As of December 31, 1940

THE privately-owned Jamaica Water Supply Company serves an area in and around Jamaica, N.Y., which comprises most of the Fourth Ward and parts of the Second and Third Wards of Queens Borough (a part of New York City) and six villages and surrounding territory in the towns of Hempstead and North Hempstead in Nassau County. The total service area covers approximately 40 sq.mi. and contains a population of about 400,000.

The area served is predominantly residential in character, suburban to New York City. It does, however, contain a considerable number of small diversified industries. As of the date of the study there were 86,148 services, 7,623 of which were metered. The distribution system consisted of 643 mi. of mains, from 2 to 24 in. in diameter, with 7,886 hydrants attached. The average pumpage during 1940 was 29.5 mgd., with a peak day of 41.9 mgd. Average use approximated 75 gpd. per capita.

Development of the Existing System

The Jamaica Water Supply Company was incorporated on Apr. 21,

TABLE 1

Summary of Mains

Jamaica, New York

Size, *in.*	Kind	No. of Feet Installed	Percentage of Total	No. of Feet Retired	Percentage of Total	No. of Feet in Service	Percentage of Total	Year of First Installation	Average Age, *yr.*
4	Cast-iron unlined	111,985	3.2	28,853	29.7	83,132	2.5	1887	42.7
6		1,397,003	40.5	45,831	47.2	1,351,172	40.3	1887	22.9
8		1,518,359	44.0	12,855	13.2	1,505,504	44.9	1887	14.0
10		30,420	0.9	2,078	2.1	28,342	0.8	1887	33.9
12		310,243	9.0	6,606	6.8	303,637	9.0	1887	15.1
14		10,092	0.3	0	0.0	10,092	0.3	1910	22.4
16		73,607	2.1	944	1.0	72,663	2.2	1904	14.3
18		72	0.0	0	0.0	72	0.0	1930	10.5
20		1,332	0.0	0	0.0	1,332	0.0	1934	6.5
24		268	0.0	0	0.0	268	0.0	1935	5.5
Total		3,453,381	100.0	97,167	100.0	3,356,214	100.0		18.6
Percentage of Total		100.00		2.81		97.19			
Average Size, *in.*		7.6		6.3		7.7			

TABLE 1 (contd.)

Mortality Survival Ratios

Size, *in.*	No. of Feet	Period Covered, *yr.*	Percentage
4	111,985	53.5	71.470
6	1,397,003	53.5	92.359
8	1,518,359	53.5	93.049
10 and 12	340,663	53.5	87.609
Over 12	85,371	36.5	96.963
Total	3,453,381		

1887, to supply water to the town of Jamaica in Queens County, New York. It was merged with the Jamaica Township Water Company, organized in 1888, on Aug. 20, 1902. The Company not only expanded its territory in Queens County, but in 1899 extended its mains into Nassau County. In 1898, the city of New York annexed the company's territory in Queens County, which became Queens Borough and to which service is still rendered by the company.

The water sources of the company consist of 43 Layne gravel-wall wells located in various parts of its territory. Their depths vary from 63 to 614 ft. They have a daily average yield of 65 mil.gal. The water is pumped from the wells by motor-driven centrifugal deep well pumps. Twenty-seven of the wells are pumped directly into the distribution system. The remaining sixteen pump into steel reservoirs or tanks from which motor driven units (one gasoline-engine-driven) pump to the distribution system. Water from four wells is treated in a slow sand filter and that from two wells in pressure filters. The supply at most stations is also treated with chlorine.

The storage reservoirs consist of four low-pressure steel tanks of 5.876-mil.gal. total capacity and eleven high-

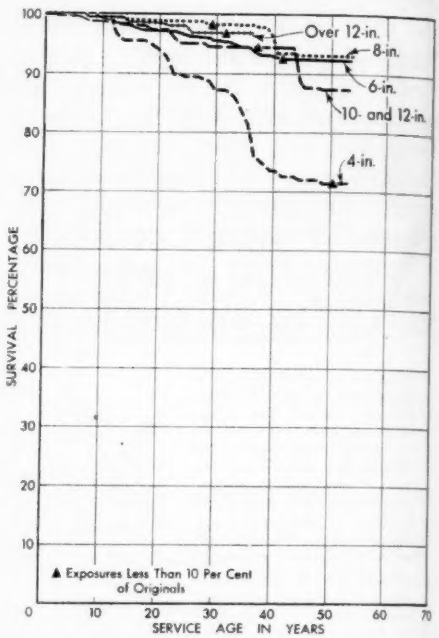

FIG. 1. Mortality Survival Curve—4–24-in. Cast-Iron Unlined Mains—Jamaica, New York

BASE: Feet SIZE	SURVIVAL: 1887–1940 EXPOSURES	RETIREMENTS
in.	*ft.*	*ft.*
4	111,985	28,853
6	1,397,003	45,831
8	1,518,359	12,855
10 and 12	340,663	8,684
Over 12	85,371	944

pressure steel tanks and standpipes of 9.856-mil.gal. capacity.

The pipe system is composed almost entirely of Class B cast-iron pipe.

Basis of Study

Work orders showing the record of installations and retirements of mains are complete since 1917 covering the record of 13 per cent of the existing mains. Prior to 1917, the record of main installation and retirement was obtained from a comprehensive study of old maps and records, dates of consumer applications, hydrant numbers, etc.

Mortality Survival Study

Mortality studies were made of cast-iron mains. Table 1 is a summary of the pipe installed, retired and that still in service, as well as other pertinent data. Figure 1 shows the mortality survival curves covering the record of the amounts and sizes of pipe grouped as shown.

Causes of Retirement

While no special study was made of causes of retirement, it is a known fact in the experience of the company that the larger portion of the retirements were due to "requirements of public authorities." The territory has had a rapid growth and Queens Borough particularly has constantly undergone changes in street locations, widths and grades and construction of sewers, subways, super-highways, parks and housing developments—all requiring retirements of mains.

Acknowledgment

The collection and compilation of data in Jamaica were under the direction of Carter H. Lamb, Vice President, who at the time of the study was Valuation Engineer of the Company.

Summary of Installations and Retirements
Jamaica, New York

Mains

4-in. Cast-Iron Unlined Mains

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1887	443	443	0
1891	25,151	15,639	9,512
1892	12,997	10,947	2,050
1893	5,776	3,376	2,400
1894	8,876	5,610	3,266
1895	3,374	2,610	764
1896	5,364	4,812	552
1897	2,727	2,727	0
1898	7,750	2,299	5,451
1899	19,117	17,434	1,683
1900	1,645	685	960
1902	291	19	272
1904	2,670	2,670	0
1905	6,367	5,756	611
1906	1,525	1,022	503
1910	3,898	3,078	820
1911	380	380	0
1912	3	0	3
1913	350	350	0
1915	453	453	0

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1917	48	48	0
1919	35	35	0
1920	3	3	0
1921	24	24	0
1922	60	60	0
1923	71	71	0
1924	53	47	6
1925	34	34	0
1926	141	141	0
1927	222	222	0
1928	1,544	1,544	0
1929	3	3	0
1931	68	68	0
1932	4	4	0
1935	11	11	0
1936	295	295	0
1938	195	195	0
1940	17	17	0
Total	111,985	83,132	28,853

Retirements by Years

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1891	1,305	1904	1,111	1910	70	1912
	2,145	1913	70	1922	180	1923
	397	1925	1,609	1926	1,300	1927
	652	1928	398	1932	40	1935
	235	1939				
1892	259	1910	537	1912	389	1926
	865	1931				
1893	30	1916	374	1917	1,292	1927
	704	1931				
1894	70	1905	200	1912	237	1921
	528	1926	823	1927	93	1928
	1,302	1930	13	1938		
1895	458	1904	15	1935	291	1939

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1896	22	1928	471	1932	59	1936
1898	2,857	1910	1,583	1927	620	1931
	391	1939				
1899	60	1904	43	1921	1,560	1935
	5	1938	15	1940		
1900	500	1928	460	1936		
1902	272	1939				
1905	611	1926				
1906	503	1927				
1910	250	1927	570	1931		
1912	3	1935				
1924	6	1928				

6-in. Cast-Iron Unlined Mains

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1887	23,250	21,082	2,168
1888	4,477	4,477	0
1891	27,656	24,487	3,169
1892	24,743	21,367	3,376
1893	4,951	4,017	934
1894	22,001	16,126	5,875
1895	9,329	9,087	242

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1896	8,621	6,678	1,943
1897	5,290	5,290	0
1898	3,552	605	2,947
1899	26,450	24,338	2,112
1900	7,363	6,752	611
1901	4,974	4,974	0
1902	4,296	4,012	284

6-in. Cast-Iron Unlined Mains (contd.)

Year Installed	Feet Installed	In Service	Retired
1903	15,340	13,864	1,476
1904	23,258	22,637	621
1905	28,522	26,494	2,028
1906	9,559	9,495	64
1907	3,517	2,497	1,020
1908	51,191	50,560	631
1909	38,443	36,977	1,466
1910	60,420	59,007	1,413
1911	85,942	84,588	1,354
1912	59,900	59,309	591
1913	37,624	36,696	928
1914	5,492	4,529	963
1915	7,367	7,183	184
1916	7,527	7,235	292
1917	6,359	6,334	25
1918	4,888	4,888	0
1919	7,782	7,737	45
1920	4,108	4,098	10
1921	16,782	16,598	184
1922	35,400	35,395	5
1923	75,996	75,439	557
1924	101,912	99,420	2,492
1925	128,374	127,097	1,277
1926	93,045	92,567	478
1927	82,845	82,563	282
1928	57,068	55,921	1,147
1929	38,559	37,586	973
1930	23,133	22,702	431
1931	33,549	32,622	927
1932	10,028	10,015	13
1933	7,615	7,610	5
1934	7,759	7,759	0
1935	4,035	3,758	277
1936	3,020	3,009	11
1937	6,181	6,181	0
1938	5,350	5,350	0
1939	17,538	17,538	0
1940	14,622	14,622	0
Total	1,397,003	1,351,172	45,831

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1887	853	1904	648	1910	182	1915
	440	1928	45	1937		
1891	648	1906	985	1927	1,084	1928
	41	1929	405	1931	6	1939
1892	1,959	1904	1,070	1905	311	1925
	10	1936	16	1939	10	1940
1893	934	1906				
1894	3,165	1904	2,215	1910	94	1912
	388	1925	10	1938	3	1939
1895	236	1904	6	1935		
1896	600	1905	88	1915	532	1928
	723	1929				
1898	285	1904	2,658	1910	4	1936
1899	1,826	1912	201	1935	20	1936
	41	1937	24	1939		
1900	144	1919	452	1928	15	1938
1902	284	1927				
1903	355	1911	1,121	1928		
1904	291	1931	3	1935	327	1940
1905	265	1924	272	1928	827	1929
	6	1935	2	1937	656	1939
1906	60	1916	4	1936		
1907	290	1927	730	1928		
1908	220	1924	18	1932	74	1935
	11	1936	7	1937	276	1938
	25	1939				
1909	343	1931	334	1932	18	1936
	771	1938				
1910	48	1935	14	1936	3	1937
	1,348	1939				
1911	17	1930	218	1931	5	1935
	15	1936	297	1937	12	1938
	525	1939	265	1940		
1912	15	1920	237	1922	17	1932
	39	1935	7	1937	276	1938
1913	200	1924	712	1932	5	1936
	3	1938	8	1939		
1914	946	1923	17	1939		
1915	184	1933				
1916	292	1928				
1917	25	1940				
1919	42	1934	3	1937		
1920	10	1935				
1921	180	1933	4	1937		
1922	2	1936	3	1938		
1923	17	1937	540	1939		
1924	493	1927	905	1928	63	1935
	12	1936	1	1937	1	1938
	1,017	1939				
1925	789	1927	230	1934	25	1935
	15	1936	9	1937	198	1939
	11	1940				
1926	15	1935	10	1936	214	1938
	32	1939	207	1940		
1927	204	1929	51	1935	4	1936
	23	1939				
1928	546	1934	125	1935	54	1937
	422	1940				
1929	5	1935	6	1936	962	1939
1930	3	1936	428	1940		
1931	6	1936	431	1939	490	1940
1932	5	1935	8	1938		
1933	5	1936				
1935	4	1937	13	1939	260	1940
1936	1	1937	10	1938		

8-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1887	3,175	2,993	182
1888	3,140	3,140	0
1891	16,316	15,673	643
1892	2,636	2,636	0
1893	10,240	10,240	0
1896	416	413	3
1899	10,102	8,413	1,689
1901	769	769	0
1902	11,663	11,663	0
1903	5,461	5,439	22
1904	4,730	4,660	70
1905	5,345	5,345	0
1907	3,659	3,659	0
1908	10,189	10,189	0
1909	13,123	13,117	6
1910	8,059	8,035	24
1911	11,080	10,203	877
1912	32,833	32,814	19
1913	8,833	8,833	0
1914	603	597	6
1915	2,382	2,382	0
1916	6,373	6,373	0
1917	1,474	1,474	0
1918	996	992	4
1919	4,748	4,748	0
1920	4,410	4,405	5
1921	12,890	12,885	5
1922	26,082	25,899	183
1923	48,518	48,175	343
1924	89,364	89,096	268
1925	160,884	160,384	500
1926	171,170	169,513	1,657
1927	154,548	153,593	955
1928	112,342	110,942	1,400
1929	75,514	73,842	1,672
1930	68,060	67,797	263
1931	71,233	71,166	67
1932	32,566	31,836	730
1933	14,444	14,382	62
1934	23,766	23,299	467
1935	19,511	19,221	290
1936	34,475	34,455	20
1937	45,904	45,498	406
1938	57,266	57,261	5
1939	63,678	63,666	12
1940	53,389	53,389	0
Total	1,518,359	1,505,504	12,855

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1887	181	1931	1	1936		
1891	228	1928	415	1930		
1896	3	1937				
1899	12	1936	2	1937	1,675	1939
1903	22	1936				
1904	6	1936	12	1937	52	1940
1909	6	1936				
1910	24	1936				
1911	256	1931	6	1937	615	1939
1912	4	1935	12	1936	3	1937
1914	6	1935				
1918	4	1936				
1920	5	1935				
1921	5	1938				
1922	60	1925	115	1931	4	1936
	4	1937				
1923	12	1937	331	1939		
1924	252	1928	14	1936	2	1937
1925	31	1935	19	1936	82	1937
	337	1939	31	1940		

Year Installed	Feet	Year	Feet	Year	Feet	Year
1926	137	1931	175	1932	24	1933
	14	1935	83	1936	13	1937
	1,211	1939				
1927	285	1929	9	1935	18	1936
	3	1937	640	1939		
1928	209	1934	3	1935	9	1936
	8	1937	1,171	1939		
1929	84	1932	95	1936	58	1937
	625	1938	810	1939		
1930	12	1935	200	1936	5	1937
	5	1938	41	1939		
1931	4	1935	23	1906	40	1940
1932	546	1935	171	1936	13	1939
1933	47	1937	15	1940		
1934	11	1936	291	1939	165	1940
1935	5	1937	120	1939	165	1940
1936	3	1937	9	1939	8	1940
1937	9	1938	397	1939		
1938	5	1939				
1939	12	1940				

10-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1887	4,821	4,055	766
1888	2,731	2,731	0
1891	3,229	2,416	813
1904	6,679	6,679	0
1912	2,641	2,161	480
1917	836	836	0
1919	2	0	2
1920	2	2	0
1922	2,599	2,595	4
1923	4,336	4,336	0
1924	1,416	1,413	3
1925	47	47	0
1926	3	3	0
1927	17	17	0
1928	19	19	0
1929	91	91	0
1930	117	107	10
1931	132	132	0
1932	17	17	0
1933	29	29	0
1934	557	557	0
1935	11	11	0
1936	5	5	0
1938	20	20	0
1939	63	63	0
1940	0	0	0
Total	30,420	28,342	2,078

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1887	740	1910	26	1932
1891	813	1935		
1912	474	1934	6	1936
1919	2	1935		
1922	4	1936		
1924	3	1936		
1930	10	1938		

12-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1887	4,487	4,257	230
1904	13,358	12,867	491
1905	2,375	2,375	0
1906	3,590	3,590	0
1909	5,702	5,702	0
1910	22,723	22,114	609
1911	1,897	1,897	0
1912	7,407	6,610	797
1917	1,359	1,356	3
1918	12	12	0
1920	3	3	0
1921	288	288	0
1922	300	300	0
1923	9,046	9,046	0
1924	26,943	26,511	432
1925	19,638	19,303	335
1926	9,620	9,611	9
1927	23,272	22,957	315
1928	30,222	29,882	340
1929	23,442	21,930	1,512
1930	23,009	22,189	820
1931	8,131	7,980	151
1932	10,596	10,596	0
1933	2,174	2,162	12
1934	3,435	3,422	13
1935	3,004	3,004	0
1936	11,552	11,533	19
1937	7,145	6,639	506
1938	8,255	8,255	0
1939	17,825	17,813	12
1940	9,433	9,433	0
Total	310,243	303,637	6,606

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1887	92	1931	133	1932	5	1935
1904	491	1932				
1910	605	1928	4	1936		
1912	753	1934	11	1935	33	1937
1917	3	1935				
1924	8	1935	16	1936	18	1937
	390	1939				
1925	291	1933	44	1940		
1926	9	1939				
1927	5	1937	310	1939		
1928	2	1937	338	1939		
1929	1,437	1936	75	1939		
1930	768	1936	52	1939		
1931	147	1936	4	1939		
1933	12	1939				
1934	12	1934	1	1937		
1936	19	1939				
1937	506	1939				
1939	12	1940				

14-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1910	6,276	6,276	0
1922	348	348	0
1923	3	3	0
1927	3	3	0
1928	10	10	0
1929	1,992	1,992	0
1932	8	8	0
1935	516	516	0
1938	684	684	0
1940	252	252	0
Total	10,092	10,092	0

16-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1904	5,063	4,872	191
1910	5,222	4,775	447
1912	557	557	0
1918	436	436	0
1922	4,944	4,684	260
1923	1,260	1,242	18
1924	4,396	4,396	0
1925	9,590	9,586	4
1927	1,668	1,668	0
1928	8,052	8,052	0
1929	845	831	14
1930	1,835	1,835	0
1931	7,540	7,540	0
1932	12,993	12,985	8
1933	766	764	2
1934	339	339	0
1935	822	822	0
1938	4,012	4,012	0
1939	2,244	2,244	0
1940	1,023	1,023	0
Total	73,607	72,663	944

16-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1904	185	1929	3	1936	3	1937
1910	380	1924	67	1931		
1922	256	1929				
1923	18	1938				
1925	4	1936				
1929	14	1933				
1932	8	1935				
1933	2	1940				

18-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1930	72	72	0
1940	0	0	0
Total	72	72	0

20-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1934	1,332	1,332	0
1940	0	0	0
Total	1,332	1,332	0

24-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1935	268	268	0
1940	0	0	0
Total	268	268	0

Portland, Maine—Survival and Retirement Experience With Water Works Facilities

As of December 31, 1940

THE Portland Water District is a public municipal corporation, created by an act of the legislature of the state of Maine, approved Mar. 27, 1907. The district supplies an area about 20 mi. square, including, besides the city of Portland, the cities of South Portland and Westbrook and the towns of Gorham, Cape Elizabeth, Windham, Scarboro, Falmouth and Cumberland. Peaks Island, formerly supplied by a private company, is now also supplied by the water district.

The District is entirely separate from the city governments of the cities served and is controlled by a board of five trustees, elected by popular vote, four from the city of Portland and one from South Portland.

Within the service territory, at the date of the study, there were 23,524 services furnishing water to an estimated 109,000 persons. Consumption during 1940 averaged 14.3 mgd., or about 131 gpd. per capita.

Development of the Existing System

Construction of the system was started in 1868 by the Portland Water Company, a private company which continued to operate the works until 1908, when the works were purchased by the District.

The source of the water supply is Sebago Lake, about 16 mi. north of Portland. This lake, with an elevation of 265 ft. above sea level, has a surface area of 45.6 sq.mi. and a drainage area of about 436 sq.mi. The water from the lake is soft, clear and unpolluted and receives no other treatment than the application of sodium hypochlorite, commenced in 1914, and chlorine, started in 1925.

The first supply pipe laid in 1868–69 was made of sheet iron, coated and lined with natural cement, and was 20 in. in diameter. A second main, of similar construction, partly 26 in. and partly 24 in., was installed, parallel to the first main, in 1879. More than one-third of these mains were still in service at the date of the study.

In addition to the portions of the cement mains still in service the distribution system is supplied by a 42-in. cast-iron, a 30-in. cast-iron and a 48-in. reinforced concrete transmission main, variously interconnected and branching to parts of the system serving Portland and South Portland and, along their routes, Windham, Gorham and Westbrook.

There are two reservoirs in the system which were formerly used as equalizing reservoirs on the low service but are now kept filled for reserve.

Bramhall Reservoir, located in the southwestern part of the city, was constructed in 1868 in excavation and earth embankment, with sides lined with masonry and the bottom with clay. It has a capacity of 8 mil.gal. Munjoy Reservoir, of similar construction, located in the southeastern part of the city was built in 1888 and has a capacity of 20 mil.gal.

In addition there are twelve standpipes in the system, the first being built in 1892. All standpipes built in the

system are still in service except one of reinforced concrete.

The distribution system contains approximately 425 mi. of mains, from ½ to 36 in. in diameter, 3,361 valves and 2,056 hydrants. The services are 50 per cent metered, with 11,744 meters in service.

The greater part of the mains consists of tar-coated, bell-and-spigot cast-iron pipe laid in a 5-ft. trench. The older service pipes are largely galvanized steel, about one-half of which have been replaced recently with copper.

Basis of Study

The records of the installation and retirement of pipe were very well kept by the company which built and operated the water works from 1869 to

TABLE 1

SUMMARY OF MAINS
PORTLAND, MAINE

Size, *in.*	Kind	No. of Feet Installed	Percentage of Total	No. of Feet Retired	Percentage of Total	No. of Feet in Service	Percentage of Total	Year of First Installation	Average Age, *yr.*
4	Cast-iron unlined	39,128	2.0	14,325	5.1	24,803	1.5	1869	51.7
6		623,014	32.2	106,250	38.0	516,764	31.3	1869	31.8
8		375,227	19.4	42,707	15.3	332,520	20.1	1869	23.4
10		38,752	2.0	1,551	0.5	37,201	2.3	1869	34.5
12		157,926	8.2	8,599	3.1	149,327	9.0	1869	37.0
16		31,163	1.6	6,790	2.4	24,373	1.5	1869	38.4
20		43,404	2.2	521	0.2	42,883	2.6	1887	26.8
24		3,622	0.2	176	0.1	3,446	0.2	1879	24.4
30		34,728	1.8	4,133	1.5	30,595	1.9	1900	38.8
42		75,749	3.9	0	0	75,749	4.6	1912	28.5
48		134	0.0	0	0	134	0.0	1925	15.5
6	Cast-iron cement-lined	59,017	3.1	141	0.0	58,876	3.6	1925	10.8
8		104,825	5.4	18	0.0	104,807	6.3	1926	11.6
10		320	0.0	0	0	320	0.0	1928	11.6
12		49,644	2.6	0	0	49,644	3.0	1927	11.8
16		19,666	1.0	0	0	19,666	1.2	1926	11.3
20		9,571	0.5	0	0	9,571	0.6	1926	11.2
24		12,722	0.7	0	0	12,722	0.8	1927	10.9
30		5,355	0.3	0	0	5,355	0.3	1927	13.5
8	Cast-iron bituminous-lined	15,229	0.8	0	0	15,229	0.9	1939	1.5
12		8,641	0.4	0	0	8,641	0.5	1939	1.5
16		4,330	0.2	0	0	4,330	0.3	1939	1.5
30		3,942	0.2	0	0	3,942	0.2	1939	1.5
42	Concrete	13,596	0.7	0	0	13,596	0.8	1931	9.5
48		53,202	2.8	0	0	53,202	3.2	1931	3.8
36	Steel	3,730	0.2	0	0	3,730	0.2	1931	9.5
20	Wrought-iron cement-lined	72,698	3.8	47,469	17.0	25,229	1.5	1869	71.5
24		55,632	2.9	36,253	12.9	19,379	1.2	1879	61.5
26		18,072	0.9	10,872	3.9	7,200	0.4	1879	61.5
TOTAL		1,933,039	100.0	279,805	100.0	1,653,234	100.0		27.0
Percentage of Total		100.00		14.47		85.53			
Average Size, *in.*		12.70		12.53		12.73			

TABLE 1 (contd.)

Mortality Survival Ratios

Size, *in.*	Kind	Number of Feet	Period Covered, *yr.*	Percentage
4	Cast-iron unlined	39,128	71.5	48.489
6		623,014	70.5	68.057
8		375,227	58.5	77.479
10 and 12		196,678	62.5	92.341
Over 12		188,800	61.5	90.668
6	Cast-iron cement-lined	59,017	15.5	99.761
8		104,825	14.5	99.983
10–30		97,278	14.5	100.000
8–16	Cast-iron bituminous-lined	28,200	1.5	100.000
30–48	Concrete	70,740	9.5	100.000
36	Steel	3,730	9.5	100.000
20–26	Wrought-iron cement-lined	146,402	71.5	25.080
TOTAL		1,933,039		

TABLE 2

SUMMARY OF METERS

PORTLAND, MAINE

Size, *in.*	Kind	Number Installed	Number Identified	Number Retired	Number in Service	Average Age, *yr.*
3/8	Piston	4	4	1	3	8.5
5/8		9,025	9,004	99	8,905	17.2
3/4		515	511	18	493	24.8
1		305	303	12	291	21.6
1½		183	182	5	177	21.0
2		371	365	32	333	18.5
3		13	13	1	12	20.6
4		12	12	3	9	13.6
5/8	Disc	714	685	642	43	16.7
3/4		62	61	60	1	37.5
1		9	8	8	0	—
1½		4	4	4	0	—
2		15	14	13	1	28.5
3		2	1	1	0	—
4		3	2	1	1	21.5
6		5	3	2	1	29.5
8		4	3	1	2	28.5
12		2	1	1	0	—
3	Compound	1	1	0	1	15.5
4		9	9	0	9	17.1
6		6	6	0	6	5.5
8		4	4	0	4	14.8
2	Current	31	31	16	15	26.9
3		4	3	0	3	45.8
4		11	11	3	8	39.3
6		7	7	1	6	36.0
TOTAL		11,321	11,248	924	10,324	17.8

TABLE 2 (contd.)

Mortality Survival Ratios

Size, *in.*	Kind	Number	Period Covered, *yr.*	Percentage
$\frac{3}{8}$ and $\frac{5}{8}$	Piston	9,008	49.5	97.640
$\frac{3}{4}$–4	Piston	1,386	46.5	91.174
$\frac{5}{8}$	Disc	685	38.5	0.859
$\frac{3}{4}$–12	Disc	97	37.5	1.531
2–8	Compound and Current	72	52.5	55.569
TOTAL		11,248		

1908 and these records were continued under the present management. The pipe record books show the location, date and size of each section of pipe installed and retired.

The record of meter installation and retirement is substantially complete from the date of the first installation.

The records of the installation and retirement of valves, hydrants and services are not complete. Generally valves were installed and retired with the pipe in which located, but details are not available.

Mortality Survival Study

Mortality studies were made of mains and meters. Table 1 is a summary of the pipe installed, the amount retired and that still in service, as well as other pertinent data. Figure 1 shows the mortality survival curves covering the record of the mains grouped as shown.

Table 2 is a summary of the installation and retirement of meters, with Figure 2 representing the applicable mortality curves.

Given below is a summary of the standpipes and elevated tanks which have been erected in the system.

Causes of Retirement

The causes of retirement of mains were not determined in the study.

Acknowledgment

The collection and compilation of data in Portland were under the general supervision of Harry U. Fuller, Chief Engineer of the District and a member of the Committee on Survival and Retirement Experience With Water Works Facilities.

SUMMARY OF STANDPIPES AND TANKS
PORTLAND, MAINE

South Portland—Open wrought-iron standpipe, 36 ft. in diameter, 77 ft. high; capacity 602,000 gal. Erected in 1892 and still in service.

Gorham—Open steel standpipe, 35 ft. in diameter, 50 ft. high; capacity 360,000 gal. Erected in 1896 and still in service.

Portland—Munjoy Hill—Open steel standpipe, 40 ft. in diameter, 75 ft. high; capacity 653,000 gal. Erected in 1904 and still in service.

Peaks Island—Open concrete standpipe, 28 ft. in diameter, 40 ft. high; capacity 175,000 gal. Erected in 1909 and retired 1934 because of disintegration of concrete.

Peaks Island—Open steel standpipe, replacing above, 40 ft. in diameter, 50 ft. high; capacity 470,000 gal. Erected in 1934 and still in service.

Falmouth Foreside—Open steel standpipe, 40 ft. in diameter, 55 ft. high; capacity 517,000 gal. Erected in 1923 and still in service.

Prouts Neck—Open steel standpipe, 15 ft. in diameter, 50 ft. high; capacity 66,000 gal. Erected in 1902 and still in service.

Scarboro (Oak Hill)—Open steel standpipe, 35 ft. in diameter, 90 ft. high; capacity 646,000 gal. Erected in 1926 and still in service.

Scarboro (Dunstan)—Open steel standpipe, 25 ft. in diameter, 70 ft. high; capacity 258,000 gal. Erected in 1929 and still in service.

Great Diamond Island—Open, steel standpipe, 30 ft. in diameter, 25 ft. high; capacity 132,500 gal. Erected in 1900 and still in service.

Newhall (South Windham)—Open steel standpipe, 30 ft. in diameter, 45 ft. high; capacity 237,800 gal. Erected in 1938 and still in service.

Westbrook (Brook Street)—Open, steel standpipe, 30 ft. in diameter, 55 ft high; capacity 290,000 gal. Erected in 1939 and still in service.

North Windham (Halls Point)—Open steel standpipe, 12 ft. in diameter, 12 ft. high; capacity 10,000 gal. Erected in 1939 and still in service.

North Windham—Elliptical bottom, covered elevated steel tank, 32 ft. in diameter, 23 ft. high, on tower; capacity 200,000 gal. Erected in 1938 and still in service.

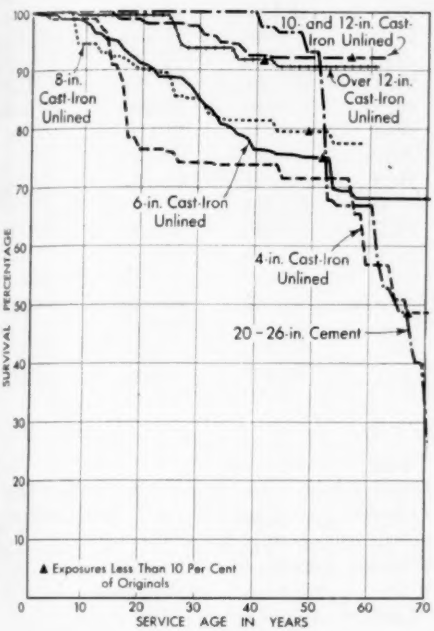

FIG. 1. Mortality Survival Curve—4–48-in. Cast-Iron Unlined and 20–26-in. Wrought-Iron Cement-Lined Mains—Portland, Maine

BASE: Feet SURVIVAL: 1869–1940

SIZE	KIND	EXPOSURES	RETIREMENTS
in.		*ft.*	*ft.*
4	Cast-Iron Unlined	39,128	14,325
6		623,014	106,250
8		375,227	42,707
10 and 12		196,678	10,150
Over 12		188,800	11,620
20–26	Wrought-Iron Cement-Lined	146,402	94,594

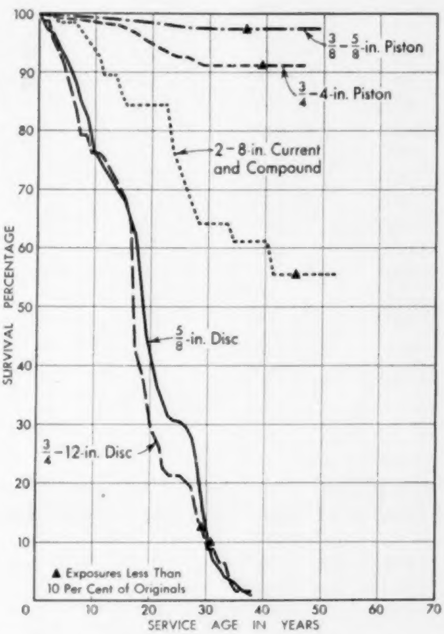

FIG. 2. Mortality Survival Curve—3/8–12-in. Meters—Portland, Maine

BASE: Unit SURVIVAL: 1886–1940

SIZE	KIND	EXPOSURES	RETIREMENTS
in.		*Units*	*Units*
3/8 and 5/8	Piston	9,008	100
3/4–4	Piston	1,386	71
5/8	Disc	685	642
3/4–12	Disc	97	91
2–8	Current and Compound	72	20

Summary of Installations and Retirements
Portland, Maine

Mains

4-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1869	6,725	46	6,679
1870	1,948	1,088	860
1871	2,176	640	1,536
1873	2,086	987	1,099
1874	1,455	1,210	245
1875	2,239	1,462	777
1877	1,088	464	624
1878	940	716	224
1879	1,115	1,115	0
1880	669	669	0
1881	828	828	0
1882	160	160	0
1883	825	44	781
1884	518	518	0
1885	2,205	2,205	0
1886	4,410	3,665	745
1887	245	245	0
1889	480	480	0
1890	75	75	0
1891	610	610	0
1892	1,711	1,711	0
1894	423	423	0
1895	280	190	90

Year Installed	Feet Installed	Feet In Service	Feet Retired
1896	94	94	0
1900	384	384	0
1901	392	392	0
1904	801	136	665
1905	19	19	0
1906	360	360	0
1908	45	45	0
1909	87	87	0
1910	649	649	0
1911	511	511	0
1913	184	184	0
1917	470	470	0
1920	31	31	0
1921	1,043	1,043	0
1928	25	25	0
1930	123	123	0
1932	699	699	0
1940	0	0	0
Subtotal	39,128	24,803	14,325
Unknown	12,763	12,763	0
Total	51,891	37,566	14,325

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1869	1,329	1883	1,173	1885	3,520	1886
	657	1888				
1870	134	1914	412	1934	314	1935
1871	1,536	1930				
1873	54	1889	1,045	1930		
1874	42	1931	203	1938		
1875	777	1889				

Year Installed	Feet	Year	Feet	Year	Feet	Year
1877	624	1889				
1878	224	1902				
1883	104	1915	677	1927		
1886	475	1889	270	1899		
1895	90	1912				
1904	665	1930				

6-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1869	23,107	0	23,107
1870	7,362	1,380	5,982
1871	4,665	4,496	169
1872	12	12	0
1873	2,405	1,103	1,302
1874	1,605	1,012	593
1877	4,704	3,829	875
1878	308	308	0

Year Installed	Feet Installed	Feet In Service	Feet Retired
1879	4,758	2,896	1,862
1880	787	246	541
1881	4,076	2,630	1,446
1883	1,211	1,099	112
1884	507	507	0
1885	8,764	3,429	5,335
1886	24,397	13,378	11,019
1887	7,400	7,109	291

6-in. Cast-Iron Unlined Mains (contd.)

Year Installed	Feet: Installed	Feet: In Service	Feet: Retired
1888	9,723	9,723	0
1889	22,344	19,890	2,454
1890	5,303	4,321	982
1891	3,751	3,576	175
1892	31,823	28,609	3,214
1893	3,347	1,859	1,488
1894	5,673	4,594	1,079
1895	16,880	15,200	1,680
1896	14,726	13,195	1,531
1897	24,161	19,393	4,768
1898	22,764	16,267	6,497
1899	11,621	4,215	7,406
1900	4,647	3,052	1,595
1901	16,539	14,853	1,686
1902	21,807	20,652	1,155
1903	2,252	2,160	92
1904	9,822	9,144	678
1905	5,088	4,511	577
1906	10,628	9,094	1,534
1907	4,436	3,373	1,063
1908	4,349	4,308	41
1909	6,685	6,685	0
1910	3,125	2,875	250
1911	10,970	5,356	5,614
1912	13,154	11,789	1,365
1913	21,480	18,791	2,689
1914	15,872	13,248	2,624
1915	33,962	33,917	45
1916	18,526	17,422	1,104
1917	11,203	11,011	192
1918	1,821	1,821	0
1919	1,338	1,338	0
1920	3,913	3,913	0
1921	14,335	14,335	0
1922	6,588	6,588	0
1923	2,688	2,688	0
1924	6,830	6,830	0
1925	17,318	17,318	0
1926	1,053	1,015	38
1927	531	531	0
1928	1,434	1,434	0
1929	107	107	0
1930	234	234	0
1931	12,540	12,540	0
1932	1,270	1,270	0
1933	304	304	0
1934	6,371	6,371	0
1935	8,569	8,569	0
1936	9,526	9,526	0
1937	10,242	10,242	0
1938	19,164	19,164	0
1939	8,911	8,911	0
1940	5,198	5,198	0
Subtotal	623,014	516,764	106,250
Unknown	13,404	13,404	0
Total	636,418	530,168	106,250

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1869	90	1883	877	1884	3,531	1885
	4,966	1886	1,303	1887	1,849	1890
	3,046	1891	26	1896	33	1897
	596	1898	1,281	1900	802	1901
	2,699	1902	381	1904	1,347	1905
	280	1911				
1870	4,010	1889	256	1891	682	1900
	408	1902	306	1903	320	1916
1871	108	1891	61	1916		
1873	987	1881	315	1886		
1874	220	1900	373	1931		
1877	875	1930				
1879	934	1889	928	1912		
1880	196	1891	345	1927		
1881	250	1891	1,196	1903		
1883	112	1903				
1885	5,335	1896				
1886	506	1900	630	1902	500	1911
	1,136	1914	4,343	1915	843	1929
	251	1930	141	1934	2,469	1939
1886	200	1940				
1887	235	1903	56	1914		
1889	234	1904	888	1921	1,332	1927
1890	458	1922	524	1926		
1891	175	1902				
1892	3,214	1931				
1893	326	1921	1,162	1927		
1894	243	1904	313	1927	523	1931
1895	139	1901	1,541	1931		
1896	550	1927	981	1931		
1897	200	1902	268	1926	4,300	1927
1898	2,415	1911	476	1918	894	1930
	1,958	1931	754	1939		
1899	5,420	1904	1,896	1927	90	1939
1900	1,595	1939				
1901	415	1918	1,271	1928		
1902	445	1912	247	1926	395	1927
	68	1930				
1903	92	1931				
1904	103	1930	575	1931		

6-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years (contd.)

Year Installed	Feet	Year	Feet	Year	Feet	Year
1905	450	1912	127	1922		
1906	1,534	1928				
1907	490	1925	573	1927		
1908	41	1928				
1910	250	1927				
1911	3,384	1922	2,230	1927		
1912	870	1922	495	1939		
1913	651	1914	134	1930	1,673	1931
1913	231	1935				
1914	349	1916	289	1926	1,902	1927
	39	1928	45	1930		
1915	45	1928				
1916	486	1927	618	1937		
1917	192	1930				
1926	38	1939				

8-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1869	9,544	0	9,544
1870	422	0	422
1882	194	194	0
1883	1,652	1,652	0
1885	2,720	2,720	0
1886	20,264	11,557	8,707
1887	3,640	3,640	0
1889	7,877	7,877	0
1891	2,919	2,919	0
1892	34,862	14,334	20,528
1893	600	600	0
1894	189	0	189
1895	14,793	14,793	0
1896	390	390	0
1897	29	29	0
1900	6,532	4,601	1,931
1901	5,337	5,337	0
1902	6,619	6,619	0
1903	1,294	1,294	0
1904	10,272	9,890	382
1905	2,980	2,980	0
1906	3,634	3,634	0
1907	90	0	90
1908	461	461	0
1909	1,933	1,933	0
1912	9,489	9,343	146
1913	10,455	10,455	0
1914	1,942	1,942	0
1915	39,500	39,263	237
1916	8,486	8,486	0
1917	3,910	3,379	531
1918	2,278	2,278	0
1919	1,334	1,334	0
1920	1,089	1,089	0
1921	13,413	13,413	0
1922	11,340	11,340	0
1923	6,531	6,531	0
1924	7,268	7,268	0
1925	11,460	11,460	0
1926	449	449	0
1927	1,089	1,089	0
1928	5,646	5,646	0
1929	2,359	2,359	0
1930	5,162	5,162	0
1931	875	875	0
1933	630	630	0
1934	5,045	5,045	0
1935	3,569	3,569	0
1936	35,367	35,367	0
1937	7,280	7,280	0
1938	21;846	21,846	0
1939	12,306	12,306	0
1940	5,862	5,862	0
Subtotal	375,227	332,520	42,707
Unknown	32,848	32,848	0
Total	408,075	365,368	42,707

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1869	1,476	1883	967	1885	1,444	1886
	2,382	1887	127	1888	332	1889
	600	1893	390	1896	859	1900
	400	1901	567	1902		
1870	422	1904				
1886	6,850	1911	1,297	1929	560	1939
1892	15,468	1900	3,730	1904	1,330	1922
1894	189	1904				
1900	841	1922	1,090	1931		
1904	382	1931				
1907	90	1931				
1912	146	1931				
1915	40	1922	197	1932		
1917	531	1930				

10-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1869	1,551	0	1,551
1881	508	508	0
1883	1,405	1,405	0
1884	16	16	0
1889	10	10	0
1895	382	382	0
1897	22	22	0
1900	20	20	0
1906	31,848	31,848	0
1915	4	4	0
1922	2,426	2,426	0
1923	560	560	0
1940	0	0	0
Total	38,752	37,201	1,551

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1869	1,306	1889	245	1899

12-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1869	4,577	0	4,577
1878	2,860	2,860	0
1879	5,234	5,234	0
1881	2,280	2,280	0
1883	2,877	2,877	0
1884	3,874	3,874	0
1885	5,889	4,288	1,601
1886	3,875	3,875	0
1887	1,960	1,960	0
1888	476	26	450
1889	7,480	7,080	400
1890	1,462	1,462	0
1891	3,610	3,610	0
1892	288	288	0
1894	391	391	0
1895	158	158	0
1896	7,072	6,862	210
1897	6,439	6,439	0
1899	2,636	2,636	0
1900	21,842	21,842	0
1902	3,696	3,696	0
1903	1,561	1,561	0
1904	10,718	10,718	0
1905	84	84	0
1906	949	949	0
1911	12,447	12,447	0
1912	1,836	1,836	0
1915	4,624	3,263	1,361
1918	1,741	1,741	0
1919	3,517	3,517	0
1922	12,547	12,547	0
1923	989	989	0
1924	7,687	7,687	0
1925	694	694	0
1926	1,906	1,906	0
1927	102	102	0
1928	3,543	3,543	0
1932	14	14	0
1937	1,821	1,821	0
1938	575	575	0
1939	1,385	1,385	0
1940	210	210	0
Total	157,926	149,327	8,599

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1869	2,187	1899	1,377	1902	1,013	1906
1885	620	1900	325	1912	554	1923
	102	1927				
1888	450	1920				
1889	400	1927				
1896	210	1931				
1915	1,361	1930				

16-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1869	6,052	0	6,052
1888	7,325	7,325	0
1889	869	869	0
1895	4,100	4,100	0
1900	1,355	1,355	0
1904	1,091	1,091	0
1912	4,920	4,920	0
1917	40	40	0
1922	4,947	4,209	738
1926	94	94	0
1930	370	370	0
1940	0	0	0
Total	31,163	24,373	6,790

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1869	5,087	1895	965	1905
1922	738	1930		

20-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1887	750	750	0
1890	160	160	0
1903	85	85	0
1904	1,650	1,650	0
1912	15,355	14,834	521
1914	13,033	13,033	0
1915	4,411	4,411	0
1917	192	192	0
1919	847	847	0
1920	448	448	0
1921	6,149	6,149	0
1929	324	324	0
1940	0	0	0
Total	43,404	42,883	521

Retirements by Years

Year Installed	Feet	Year
1912	521	1939

24-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1879	130	130	0
1884	176	0	176
1890	50	50	0
1901	157	157	0
1919	3,049	3,049	0
1931	60	60	0
1940	0	0	0
Total	3,622	3,446	176

Retirements by Years

Year Installed	Feet	Year
1884	176	1927

30-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1900	26,726	26,726	0
1902	4,133	0	4,133
1912	3,623	3,623	0
1925	84	84	0
1931	10	10	0
1939	152	152	0
1940	0	0	0
Total	34,728	30,595	4,133

Retirements by Years

Year Installed	Feet	Year
1902	4,133	1927

42-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1912	75,711	75,711	0
1925	38	38	0
1940	0	0	0
Total	75,749	75,749	0

48-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1925	134	134	0
1940	0	0	0
Total	134	134	0

6-in. Cast-Iron Cement-Lined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1925	4,211	4,211	0
1926	8,592	8,592	0
1927	6,307	6,307	0
1928	2,771	2,771	0
1929	5,186	5,186	0
1930	5,480	5,480	0
1931	571	571	0
1932	13,630	13,630	0
1933	10,439	10,439	0
1934	1,706	1,565	141
1935	124	124	0
1940	0	0	0
Total	59,017	58,876	141

Retirements by Years

Year Installed	Feet	Year
1934	141	1939

8-in. Cast-Iron Cement-Lined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1926	15,680	15,662	18
1927	23,593	23,593	0
1928	11,527	11,527	0
1929	12,189	12,189	0
1930	12,871	12,871	0
1931	15,066	15,066	0
1932	8,325	8,325	0
1933	4,828	4,828	0
1934	223	223	0
1935	523	523	0
1940	0	0	0
Total	104,825	104,807	18

Retirements by Years

Year Installed	Feet	Year
1926	18	1927

10-in. Cast-Iron Cement-Lined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1928	44	44	0
1929	276	276	0
1940	0	0	0
Total	320	320	0

12-in. Cast-Iron Cement-Lined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1927	22,894	22,894	0
1928	3,930	3,930	0
1929	4,700	4,700	0
1930	8,567	8,567	0
1931	6,681	6,681	0
1933	2,150	2,150	0
1934	527	527	0
1935	195	195	0
1940	0	0	0
Total	49,644	49,644	0

16-in. Cast-Iron Cement-Lined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1926	2,658	2,658	0
1927	5,043	5,043	0
1929	399	399	0
1930	1,570	1,570	0
1931	9,996	9,996	0
1940	0	0	0
Total	19,666	19,666	0

20-in. Cast-Iron Cement-Lined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1926	1,240	1,240	0
1927	2,205	2,205	0
1929	120	120	0
1930	1,361	1,361	0
1931	4,456	4,456	0
1932	189	189	0
1940	0	0	0
Total	9,571	9,571	0

24-in. Cast-Iron Cement-Lined Mains

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1927	1,848	1,848	0
1928	63	63	0
1930	10,218	10,218	0
1931	401	401	0
1932	192	192	0
1940	0	0	0
Total	12,722	12,722	0

30-in. Cast-Iron Cement-Lined Mains

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1927	5,355	5,355	0
1940	0	0	0
Total	5,355	5,355	0

8-in. Cast-Iron Bituminous-Lined Mains

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1939	15,229	15,229	0
1940	0	0	0
Total	15,229	15,229	0

12-in. Cast-Iron Bituminous-Lined Mains

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1939	8,641	8,641	0
1940	0	0	0
Total	8,641	8,641	0

16-in. Cast-Iron Bituminous-Lined Mains

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1939	4,330	4,330	0
1940	0	0	0
Total	4,330	4,330	0

30-in. Concrete Mains

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1939	3,942	3,942	0
1940	0	0	0
Total	3,942	3,942	0

42-in. Concrete Mains

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1931	13,596	13,596	0
1940	0	0	0
Total	13,596	13,596	0

48-in. Concrete Mains

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1931	15,126	15,126	0
1939	38,076	38,076	0
1940	0	0	0
Total	53,202	53,202	0

36-in. Steel Mains

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1931	3,730	3,730	0
1940	0	0	0
Total	3,730	3,730	0

20-in. Wrought-Iron Cement-Lined Mains

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1869	72,698	25,229	47,469
1940	0	0	0
Total	72,698	25,229	47,469

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1869	1,206	1912	13,130	1920	5,462	1931
	1,835	1933	7,545	1936	3,340	1937
	14,951	1939				

24-in. Wrought-Iron Cement-Lined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1879	55,632	19,379	36,253
1940	0	0	0
Total	55,632	19,379	36,253

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1879	3,942	1919	5,100	1927	24,090	1931
	1,081	1933	2,040	1940		

26-in. Wrought-Iron Cement-Lined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1879	18,072	7,200	10,872
1940	0	0	0
Total	18,072	7,200	10,872

Retirements by Years

Year Installed	Feet	Year
1879	10,872	1940

Meters

$\frac{3}{8}$-in. Piston Meters

Year Installed	Number Installed	Number In Service	Number Retired
1897	1	0	1
1931	1	1	0
1932	1	1	0
1933	1	1	0
1940	0	0	0
Total	4	3	1

Retirements by Years

Year Installed	Number	Year
1897	1	1899

$\frac{5}{8}$-in. Piston Meters

Year Installed	Number Installed	Number In Service	Number Retired
1886	6	0	6
1888	5	0	5
1889	2	0	2
1890	3	0	3
1891	2	2	0
1892	7	3	4
1893	2	1	1
1894	1	1	0
1895	3	1	2
1896	10	9	1
1897	1	0	1
1898	93	82	11
1899	235	221	14
1900	122	116	6
1901	142	134	8
1902	55	53	2
1903	36	34	2
1904	402	399	3
1905	376	368	8
1906	96	92	4
1907	2	1	1
1908	1	1	0
1909	1	0	1
1910	7	5	2
1911	2	1	1
1912	5	0	5
1913	2	2	0
1914	3	2	1
1915	57	57	0
1916	120	120	0
1917	84	83	1
1918	111	111	0
1919	79	79	0
1920	210	210	0
1921	143	142	1
1922	142	142	0
1923	310	310	0
1924	422	422	0
1925	397	397	0
1926	1,198	1,198	0
1927	591	589	2
1928	1,246	1,245	1
1929	391	391	0
1930	333	333	0

⅝-in. Piston Meters (contd.)

Year Installed	Number Installed	Number In Service	Number Retired
1931	392	392	0
1932	196	196	0
1933	12	12	0
1934	1	1	0
1935	1	1	0
1937	126	126	0
1938	304	304	0
1939	278	278	0
1940	238	238	0
Subtotal	9,004	8,905	99
Unknown	21	0	21
Total	9,025	8,905	120

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year
1886	1	1905	1	1906	1	1910
	1	1911	1	1913	1	1917
1888	1	1893	1	1904	1	1907
	1	1910	1	1915		
1889	1	1906	1	1911		
1890	1	1910	1	1915	1	1916
1892	1	1898	1	1913	1	1914
	1	1915				
1893	1	1909				
1895	1	1913	1	1916		
1896	1	1904				
1897	1	1912				
1898	1	1901	1	1902	1	1903
	2	1904	1	1906	1	1910
	2	1913	1	1914	1	1916
1899	1	1900	1	1901	1	1902
	1	1903	3	1905	1	1906
	2	1907	1	1911	1	1915
	2	1917				
1900	1	1903	1	1909	2	1912
1900	1	1916	1	1934		
1901	2	1904	1	1913	2	1914
	1	1915	1	1918	1	1924
1902	1	1910	1	1913		
1903	1	1903	1	1906		
1904	1	1905	1	1908	1	1911
1905	1	1906	2	1907	2	1908
	1	1909	1	1910	1	1913
1906	1	1906	1	1907	1	1913
	1	1916				
1907	1	1913				
1909	1	1909				
1910	1	1910	1	1920		
1911	1	1915				
1912	1	1914	4	1915		
1914	1	1923				
1917	1	1921				
1921	1	1933				
1927	1	1930	1	1933		
1928	1	1934				

¾-in. Piston Meters

Year Installed	Number Installed	Number In Service	Number Retired
1886	1	0	1
1888	3	0	3
1889	4	0	4
1894	3	2	1
1895	2	2	0
1896	3	3	0
1897	2	0	2
1898	25	22	3
1899	51	49	2
1900	25	25	0
1901	35	35	0
1902	33	32	1
1903	2	2	0
1904	7	6	1
1905	14	14	0
1906	2	2	0
1907	1	1	0
1908	1	1	0
1909	1	1	0
1915	28	28	0
1916	55	55	0
1917	1	1	0
1920	15	15	0
1921	10	10	0
1922	14	14	0
1923	17	17	0
1924	26	26	0
1926	9	9	0
1927	14	14	0
1928	3	3	0
1932	13	13	0
1933	13	13	0

¾-in. Piston Meters (contd.)

Year Installed	Number Installed	Number In Service	Number Retired	Year Installed	Number Installed	Number In Service	Number Retired
1934	6	6	0	1940	14	14	0
1935	10	10	0				
1936	14	14	0	Subtotal	511	493	18
1937	2	2	0	Unknown	4	0	4
1938	16	16	0				
1939	16	16	0	Total	515	493	22

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year	Year Installed	Number	Year	Number	Year	Number	Year
1886	1	1913					1897	1	1905	1	1913		
1888	1	1904	1	1910	1	1915	1898	1	1900	1	1914	1	1916
1889	1	1906	1	1911	1	1913	1899	1	1901	1	1908		
	1	1915					1902	1	1922				
1894	1	1916					1904	1	1914				

1-in. Piston Meters

Year Installed	Number Installed	Number In Service	Number Retired	Year Installed	Number Installed	Number In Service	Number Retired
1888	4	0	4	1921	5	5	0
1889	1	0	1	1922	13	13	0
1896	1	1	0	1923	18	18	0
1897	3	2	1	1924	14	14	0
1898	5	3	2	1925	5	5	0
1899	15	13	2	1926	17	17	0
1900	5	5	0	1927	13	13	0
1901	11	10	1	1928	6	6	0
1902	3	3	0	1929	20	20	0
1903	2	2	0	1930	5	5	0
1904	7	7	0	1932	3	3	0
1905	34	33	1	1936	12	12	0
1906	5	5	0	1937	6	6	0
1907	1	1	0	1938	7	7	0
1908	1	1	0	1939	9	9	0
1909	2	2	0	1940	16	16	0
1914	4	4	0				
1915	7	7	0	Subtotal	303	291	12
1917	8	8	0	Unknown	2	0	2
1918	1	1	0				
1919	7	7	0	Total	305	291	14
1920	7	7	0				

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year	Year Installed	Number	Year	Number	Year	Number	Year
1888	1	1905	1	1907	1	1914	1898	1	1900	1	1911		
	1	1916					1899	1	1909	1	1912		
1889	1	1907					1901	1	1901				
1897	1	1913					1905	1	1910				

1½-in. Piston Meters

Year Installed	Number Installed	In Service	Retired	Year Installed	Number Installed	In Service	Retired
1899	2	0	2	1922	10	10	0
1900	1	0	1	1923	3	3	0
1901	4	4	0	1924	23	23	0
1902	1	1	0	1925	2	2	0
1903	2	2	0	1926	1	1	0
1904	10	9	1	1927	3	3	0
1905	11	11	0	1928	10	10	0
1906	2	2	0	1929	4	4	0
1908	5	5	0	1930	5	5	0
1909	8	8	0	1932	3	3	0
1910	5	5	0	1933	2	2	0
1913	2	1	1	1938	3	3	0
1914	4	4	0	1939	5	5	0
1915	8	8	0	1940	8	8	0
1916	5	5	0		—	—	—
1917	11	11	0	SUBTOTAL	182	177	5
1918	3	3	0	Unknown	1	0	1
1919	4	4	0		—	—	—
1920	9	9	0	TOTAL	183	177	6
1921	3	3	0				

Retirements by Years

Year Installed	Number	Year	Number	Year	Year Installed	Number	Year	Number	Year
1899	1	1905	1	1916	1904	1	1914		
1900	1	1913			1913	1	1913		

2-in. Piston Meters

Year Installed	Number Installed	In Service	Retired	Year Installed	Number Installed	In Service	Retired
1888	2	0	2	1920	24	24	0
1896	3	0	3	1921	4	4	0
1897	3	0	3	1922	9	9	0
1898	5	0	5	1923	13	13	0
1899	7	0	7	1924	18	18	0
1900	4	0	4	1925	12	12	0
1901	4	4	0	1926	15	15	0
1902	7	5	2	1927	15	15	0
1903	3	3	0	1928	13	13	0
1904	4	4	0	1929	16	16	0
1905	7	7	0	1930	21	21	0
1906	3	2	1	1931	8	8	0
1907	3	2	1	1934	1	1	0
1909	1	1	0	1936	3	3	0
1910	8	6	2	1937	5	5	0
1911	2	2	0	1938	5	5	0
1912	1	1	0	1939	15	15	0
1913	2	0	2	1940	5	5	0
1914	13	13	0		—	—	—
1915	20	20	0	SUBTOTAL	365	333	32
1916	32	32	0	Unknown	6	0	6
1917	12	12	0		—	—	—
1918	6	6	0	TOTAL	371	333	38
1919	11	11	0				

2-in. Piston Meters (contd.)

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year	Year Installed	Number	Year	Number	Year	Number	Year
1888	2	1916					1900	2	1915	1	1916	1	1919
1896	1	1900	1	1916	1	1917	1902	1	1904	1	1916		
1897	1	1914	1	1918	1	1919	1906	1	1924				
1898	3	1916	1	1917	1	1919	1907	1	1907				
1899	1	1912	1	1914	3	1916	1910	1	1910	1	1925		
	1	1919	1	1920			1913	1	1916	1	1920		

3-in. Piston Meters

Year Installed	Number Installed	Number In Service	Number Retired
1901	1	1	0
1904	1	1	0
1909	1	1	0
1911	2	1	1
1913	1	1	0
1921	1	1	0
1922	1	1	0
1924	1	1	0
1926	1	1	0
1933	1	1	0
1935	1	1	0
1940	1	1	0
Total	13	12	1

Retirements by Years

Year Installed	Number	Year
1911	1	1919

4-in. Piston Meters

Year Installed	Number Installed	Number In Service	Number Retired
1896	1	0	1
1901	1	0	1
1904	1	0	1
1923	1	1	0
1924	1	1	0
1925	1	1	0
1927	2	2	0
1928	2	2	0
1929	1	1	0
1931	1	1	0
1940	0	0	0
Total	12	9	3

Retirements by Years

Year Installed	Number	Year
1896	1	1919
1901	1	1919
1904	1	1927

$\frac{5}{8}$-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired
1891	1	0	1
1892	2	0	2
1893	3	0	3
1894	4	0	4
1895	12	0	12
1896	12	0	12
1897	6	0	6
1898	1	0	1
1899	1	0	1
1901	3	0	3
1902	56	3	53
1903	96	3	93
1904	41	0	41
1905	17	0	17
1906	2	0	2
1909	3	0	3
1910	25	0	25
1911	22	1	21
1912	43	1	42
1913	53	2	51

⅝-in. Disc Meters (contd.)

Year Installed	Number Installed	Number In Service	Number Retired
1914	38	3	35
1915	100	2	98
1916	3	1	2
1920	24	3	21
1921	1	0	1
1922	1	0	1
1923	5	0	5
1924	76	7	69
1927	2	0	2
1928	3	0	3
1929	8	1	7
1933	4	0	4
1934	1	1	0
1935	1	1	0
1936	2	2	0
1938	1	0	1
1939	5	5	0
1940	7	7	0
Subtotal	685	43	642
Unknown	29	0	29
Total	714	43	671

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year
1891	1	1897				
1892	2	1898				
1893	1	1897	1	1899	1	1900
1894	2	1895	1	1899	1	1900
1895	1	1899	1	1900	1	1901
	1	1902	2	1903	1	1913
	4	1914	1	1915		
1896	1	1898	2	1899	4	1914
	1	1915	2	1916	2	1919
1897	1	1898	1	1914	1	1916
	1	1919	2	1920		
1898	1	1899				
1899	1	1902				
1901	1	1908	1	1915	1	1922
1902	2	1905	1	1910	1	1912
	1	1915	1	1917	1	1918
	15	1931	6	1932	12	1933
	2	1934	5	1935	2	1937
	3	1939	1	1940		
1903	2	1906	1	1907	1	1908
	1	1909	1	1911	1	1914
	1	1917	1	1918	2	1922
	1	1923	1	1926	16	1931
	18	1932	23	1933	4	1934
	5	1935	2	1936	3	1937
	3	1938	5	1939	1	1940
1904	1	1911	1	1914	1	1916
	2	1917	1	1920	1	1926
	6	1931	9	1932	14	1933
	3	1934	1	1935	1	1938
1905	1	1905	1	1916	3	1931
	3	1932	3	1933	1	1935
	1	1936	2	1937	2	1938
1906	1	1932	1	1933		
1909	1	1916	1	1919	1	1920
1910	2	1915	3	1916	2	1918
	6	1919	2	1920	1	1922
	1	1928	6	1931	1	1933
	1	1935				
1911	1	1914	1	1916	1	1923
	1	1925	7	1931	2	1932
	5	1933	2	1934	1	1935
1912	1	1926	18	1931	3	1932
	15	1933	1	1934	3	1935
	1	1938				
1913	2	1914	1	1917	1	1918
	1	1925	17	1931	7	1932
	12	1933	7	1935	1	1939
	2	1940				
1914	1	1914	1	1915	1	1917
	1	1918	4	1919	1	1920
	9	1931	4	1932	10	1933
	1	1934	1	1935	1	1938
1915	3	1915	1	1916	4	1918
	4	1920	1	1923	1	1924
	1	1926	1	1930	19	1931
	9	1932	34	1933	5	1934
	7	1935	1	1936	2	1937
	3	1938	2	1939		
1916	1	1918	1	1919		
1920	1	1925	4	1931	4	1932
	4	1933	2	1934	2	1935
	1	1936	1	1937	2	1939
1921	1	1932				
1922	1	1932				
1923	1	1924	1	1932	3	1933
1924	2	1928	18	1931	9	1932
	24	1933	4	1934	1	1935
	1	1936	4	1937	4	1938
	2	1939				
1927	1	1927	1	1929		
1928	1	1931	2	1932		
1929	1	1931	1	1933	1	1934
	1	1935	1	1937	1	1938
	1	1939				
1934	1	1933	1	1934	1	1936
	1	1937				
1938	1	1938				

¾-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired
1891	1	0	1
1892	1	0	1
1893	1	0	1
1903	11	1	10
1905	4	0	4
1911	1	0	1
1912	2	0	2
1913	2	0	2
1916	35	0	35
1917	3	0	3
1940	0	0	0
Subtotal	61	1	60
Unknown	1	0	1
Total	62	1	61

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year
1891	1	1895				
1892	1	1897				
1893	1	1904				
1903	4	1931	1	1932	1	1933
	2	1935	1	1937	1	1938
1905	1	1931	1	1932	1	1934
	1	1935				
1911	1	1931				
1912	1	1931	1	1932		
1913	1	1919	1	1920		
1916	1	1916	1	1928	9	1931
	2	1932	13	1933	4	1935
	1	1936	1	1937	3	1938
1917	1	1935	1	1938	1	1940

1-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired
1885	1	0	1
1897	2	0	2
1898	2	0	2
1899	1	0	1
1913	2	0	2
1940	0	0	0
Subtotal	8	0	8
Unknown	1	0	1
Total	9	0	9

1-in. Disc Meters (contd.)

Retirements by Years

Year Installed	Number	Year	Number	Year
1885	1	1889		
1897	1	1899	1	1903
1898	1	1901	1	1932
1899	1	1902		
1913	1	1920	1	1931

1½-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired
1889	1	0	1
1895	1	0	1
1913	2	0	2
1940	0	0	0
Total	4	0	4

Retirements by Years

Year Installed	Number	Year	Number	Year
1889	1	1898		
1895	1	1900		
1923	1	1931	1	1935

2-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired
1889	1	0	1
1890	1	0	1
1891	1	0	1
1892	1	0	1
1896	1	0	1
1911	1	0	1
1912	2	1	1
1913	3	0	3
1914	2	0	2
1917	1	0	1
1940	0	0	0
Subtotal	14	1	13
Unknown	1	0	1
Total	15	1	14

2-in. Disc Meters (contd.)

Retirements by Years

Year Installed	Number	Year	Number	Year
1889	1	1903		
1890	1	1903		
1891	1	1905		
1892	1	1904		
1896	1	1902		
1911	1	1916		
1912	1	1916		
1913	1	1922	2	1933
1914	2	1916		
1917	1	1933		

3-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired
1914	1	0	1
1940	0	0	0
Subtotal	1	0	1
Unknown	1	0	1
Total	2	0	2

Retirements by Years

Year Installed	Number	Year
1914	1	1920

4-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired
1915	1	0	1
1919	1	1	0
1940	0	0	0
Subtotal	2	1	1
Unknown	1	0	1
Total	3	1	2

Retirements by Years

Year Installed	Number	Year
1915	1	1922

6-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired
1911	1	1	0
1925	2	0	2
1940	0	0	0
Subtotal	3	1	2
Unknown	2	0	2
Total	5	1	4

Retirements by Years

Year Installed	Number	Year	Number	Year
1925	1	1932	1	1934

8-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired
1911	1	1	0
1912	1	0	1
1913	1	1	0
1940	0	0	0
Subtotal	3	2	1
Unknown	1	1	0
Total	4	3	1

Retirements by Years

Year Installed	Number	Year
1912	1	1927

12-in. Disc Meters

Year Installed	Number Installed	Number In Service	Number Retired
1921	1	0	1
1940	0	0	0
Subtotal	1	0	1
Unknown	1	0	1
Total	2	0	2

Retirements by Years

Year Installed	Number	Year
1921	1	1936

3-in. Compound Meters

Year Installed	Number Installed	Number In Service	Number Retired
1925	1	1	0
1940	0	0	0
Total	1	1	0

4-in. Compound Meters

Year Installed	Number Installed	Number In Service	Number Retired
1913	1	1	0
1920	2	2	0
1923	1	1	0
1924	1	1	0
1925	2	2	0
1926	1	1	0
1935	1	1	0
1940	0	0	0
Total	9	9	0

6-in. Compound Meters

Year Installed	Number Installed	Number In Service	Number Retired
1930	3	3	0
1940	3	3	0
Total	6	6	0

8-in. Compound Meters

Year Installed	Number Installed	Number In Service	Number Retired
1921	1	1	0
1927	2	2	0
1928	1	1	0
1940	0	0	0
Total	4	4	0

2-in. Current Meters

Year Installed	Number Installed	Number In Service	Number Retired
1889	3	0	3
1891	1	0	1
1892	1	0	1
1893	2	0	2
1894	1	0	1
1897	1	0	1
1899	1	0	1
1903	4	3	1
1904	1	0	1

2-in. Current Meters (contd.)

Year Installed	Number Installed	Number In Service	Number Retired
1905	5	4	1
1906	1	0	1
1907	1	0	1
1910	1	0	1
1920	1	1	0
1921	4	4	0
1922	1	1	0
1924	1	1	0
1925	1	1	0
1940	0	0	0
Total	31	15	16

Retirements by Years

Year Installed	Number	Year	Number	Year	Number	Year
1889	1	1898	1	1900	1	1903
1891	1	1932				
1892	1	1915				
1893	1	1903	1	1904		
1894	1	1928				
1897	1	1905				
1899	1	1914				
1903	1	1926				
1904	1	1928				
1905	1	1928				
1906	1	1933				
1907	1	1921				
1910	1	1917				

3-in. Current Meters

Year Installed	Number Installed	Number In Service	Number Retired
1894	1	1	0
1895	2	2	0
1940	0	0	0
Subtotal	3	3	0
Unknown	1	0	1
Total	4	3	1

4-in. Current Meters

Year Installed	Number Installed	Number In Service	Number Retired
1885	1	0	1
1888	2	1	1
1889	1	1	0
1895	2	1	1
1898	1	1	0
1899	1	1	0

4-in. Current Meters (contd.)

Year Installed	*Number Installed*	*Number In Service*	*Number Retired*
1912	1	1	0
1913	1	1	0
1916	1	1	0
1940	0	0	0
Total	11	8	3

Retirements by Years

Year Installed	*Number*	*Year*
1885	1	1911
1888	1	1913
1895	1	1923

6-in. Current Meters

Year Installed	*Number Installed*	*Number In Service*	*Number Retired*
1895	2	2	0
1900	1	0	1
1903	2	2	0
1910	1	1	0
1922	1	1	0
1940	0	0	0
Total	7	6	1

Retirements by Years

Year Installed	*Number*	*Year*
1900	1	1903

Philadelphia, Pennsylvania—Survival and Retirement Experience With Water Works Facilities

As of December 31, 1940

THE water supply of the city of Philadelphia, Pa., is provided by the municipally-owned works which represents one of the oldest water works systems in the United States. The municipal system functions as the Bureau of Water under the control of the Department of Public Works. It supplies all but a very small section of the entire occupied area of the city.

Philadelphia, the third city in size in the United States, with a population of 1,931,334 in 1940, is located in the southeastern part of Pennsylvania just above the confluence of the Schuylkill River with the Delaware River. The Schuylkill River flows through the western section of the city dividing it into two unequal areas. From early Colonial days the city has ranked among the first cities of the country. Besides being historically famous, the city ranks as an important commercial and manufacturing center, with its foundry, rolling mill and machine shop products, carpets, hats, street railway cars, knit goods and woolen goods. Shipbuilding in and around Philadelphia is also an important industry. The city covers an area of about 130 sq.mi., with ranges of elevation from tide water to 150 ft. above.

No detailed survey of the history and development of the existing water works system has been made. Water works were first developed prior to 1800. Parts of the present distribution system date from 1817, when the first cast-iron pipe was installed. An outline of the present system follows.

General Outline of the System

The Delaware and Schuylkill rivers furnish the city an adequate supply of water. This is filtered and pumped to the distribution system which is separated into nine services interconnected but valved-off at points of separation. In 1940 the draft from the two river sources was approximately 350 mgd., of which slightly more than 50 per cent was pumped from the Delaware River at its main station, Torresdale. The average daily use is approximately 160 gal. per capita. About 45 per cent of the 460,000 services are metered.

There are thirteen pumping stations, eleven of which are electrically operated and two of which are operated by steam. The main supply is secured at the Torresdale Station where it is filtered and repumped at Lardners Point and Torresdale high-service pumping stations. From the Schuylkill River, the supply is pumped at three high-lift stations, Queen Lane, Shawmont and Belmont, to sedimentation reservoirs from which it is delivered to filters. The Shawmont supply is delivered by low-lift pumping to Upper Roxborough filters and to filtered water basins which deliver by gravity to four services. To two higher services the supply is furnished by repumping and from one of these it is again pumped to a higher service.

The Torresdale plant, generally serving over half of the total consumption, has a rated capacity of 220 mgd. The Queen Lane plant has a capacity of 100 mgd., the Upper Roxborough 25 mgd., Lower Roxborough, in reserve, 10 mgd. and the Belmont filters a capacity of 70 mgd.

Pressures maintained are generally low, ranging from 25 to 50 psi. in the main service, with only a few sections outside of this service having more than 50 psi.

The distribution system consists of approximately 2,500 mi. of pipe, of which all are cast iron except about 40 mi. of steel mains 24 in. in diameter and larger. Cast-iron pipe was first installed in 1817. Early installations were uncoated, but since about 1860 all pipe laid has been tar coated. No cement-lined pipe has been installed.

Basis of Study

The records of distribution and transmission mains are maintained in card index files which were started about 1877. At or about that date an exhaustive study was made of the cast-iron pipe laid and retired prior to that time, and this formed the basis of the present card index records. Information pertaining to the date of installation and the date of retirement is definite for the greater part of the pipe system. Pipe installed prior to 1875, which could not be identified in the records as being installed or retired in a particular year, could in many instances be rather definitely assigned dates, as is later described.

Approximately seven man-months were entailed in canvassing the card index record, checking and compiling the list of mains installed and retired.

In the case of certain of the early main installations of 3- to 12-in. pipe, dates of installation and dates of retirement were assigned by the co-ordinator after a careful check of the records of each street. By comparison with intersecting streets and extensions and replacements of mains on the street having an undated pipe installation, a very close approximation could be made of the date of installation or retirement where such were lacking. The amount of such pipe is shown in Table 3.

Mortality Survival Study

From the compilation of installations and retirements a mortality study was made of the transmission and distribution mains. Table 1 is a summary of the pipe installed and retired and that remaining in service, as well as other pertinent data. Figure 1 shows the mortality survival curves covering the entire record of the pipe.

Causes of Retirement

The records of the department contain a substantially complete record of all pipe retired and information as to whether such pipe was abandoned in place or taken up. In many cases the record also indicates the reasons causing the retirements. A summary of the causes of retirement, as taken from the department records, is shown in Table 2. A breakdown of these data is not included herein, but will appear in the report of all cities, which will be published in book form. It is impossible that present officials could know what was done with pipe taken up in the period preceding their connection with the department. Pipe taken up which is in good condition is now generally reinstalled in other locations.

Subway construction and other public authority construction programs have been causes of considerable retirement of pipe and generally such removals have been salvaged and sold as scrap or re-used.

TABLE 1

Summary of Mains
Philadelphia, Pennsylvania

Size, in.	Kind	No. of Feet Installed	Percentage of Total	No. of Feet Retired	Percentage of Total	No. of Feet in Service	Percentage of Total	Year of First Installation	Average Age, yr.
3	Cast-iron unlined	212,030	1.6	197,725	16.6	14,305	0.1	1822	79.8
4	Cast-iron unlined	637,022	4.8	491,147	41.1	145,875	1.2	1823	50.4
4½	Cast-iron unlined	430	0.0	430	0.0	0	0	1817	—
6	Cast-iron unlined	7,242,534	54.2	312,352	26.1	6,930,182	57.0	1821	47.9
8	Cast-iron unlined	1,931,677	14.5	13,047	1.1	1,918,630	15.8	1822	23.0
10	Cast-iron unlined	643,038	4.8	16,268	1.4	626,770	5.2	1821	54.4
12	Cast-iron unlined	1,156,658	8.7	46,306	3.9	1,110,352	9.1	1825	32.9
16	Cast-iron unlined	290,803	2.2	4,076	0.3	286,727	2.4	1829	42.0
18	Cast-iron unlined	2,031	0.0	0	0	2,031	0.0	1890	50.5
20	Cast-iron unlined	326,411	2.4	43,858	3.7	282,553	2.3	1819	49.9
22	Cast-iron unlined	2,660	0.0	2,660	0.2	0	0	1819	—
24	Cast-iron unlined	119,523	0.9	73	0.0	119,450	1.0	1871	17.1
30	Cast-iron unlined	309,830	2.3	42,889	3.6	266,941	2.2	1819	51.3
36	Cast-iron unlined	114,653	0.9	4,693	0.4	109,960	0.9	1830	45.4
48	Cast-iron unlined	291,740	2.2	19,074	1.6	272,666	2.2	1861	39.3
60	Cast-iron unlined	4,830	0.0	0	0	4,830	0.0	1921	18.4
72	Cast-iron unlined	13,514	0.1	0	0	13,514	0.1	1930	10.5
93	Cast-iron unlined	13,150	0.1	0	0	13,150	0.1	1930	10.5
12	Steel	2,801	0.0	0	0	2,801	0.0	1930	9.8
16	Steel	120	0.0	0	0	120	0.0	1935	5.5
20	Steel	151	0.0	0	0	151	0.0	1908	32.5
30	Steel	1,590	0.0	0	0	1,590	0.0	1930	10.0
36	Steel	1,014	0.0	0	0	1,014	0.0	1921	18.5
48	Steel	31,819	0.3	0	0	31,819	0.3	1901	23.4
60	Steel	2,739	0.0	0	0	2,739	0.0	1921	19.5
93	Steel	5,651	0.0	0	0	5,651	0.1	1930	10.5
Total		13,358,419	100.0	1,194,598	100.0	12,163,821	100.0		42.3
Percentage of Total		100.00		8.94		91.06			
Average Size, in.		9.64		7.22		9.90			

Mortality Survival Ratios

Size, in.	Kind	No. of Feet	Period Covered, yr.	Percentage
3	Cast-iron unlined	212,030	118.5	4.697
4 and 4½	Cast-iron unlined	637,452	117.5	11.896
6	Cast-iron unlined	7,242,534	119.5	84.290
8	Cast-iron unlined	1,931,677	118.5	94.309
10 and 12	Cast-iron unlined	1,799,696	117.5	89.657
20	Cast-iron unlined	326,411	121.5	33.895
Over 12 (Excl. 20)	Cast-iron unlined	1,162,734	111.5	71.518
12–93	Steel	45,885	39.5	100.000
Total		13,358,419		

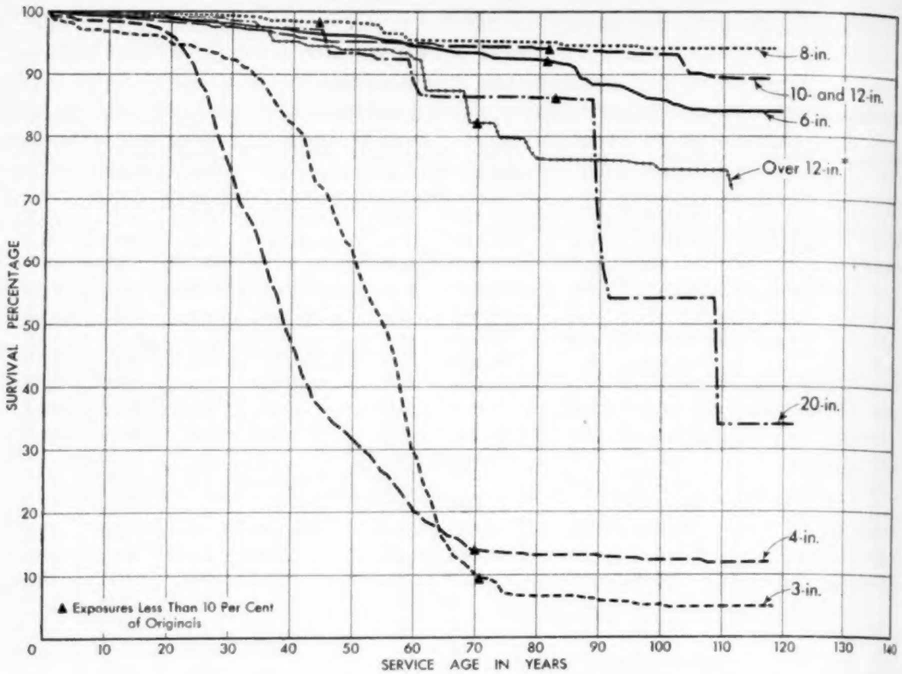

FIG. 1. Mortality Survival Curve—3–93-in. Cast-Iron Unlined Mains—Philadelphia, Pennsylvania

BASE: Feet	SURVIVAL: 1819–1940	
SIZE	EXPOSURES	RETIREMENTS
in.	*ft.*	*ft*
3	212,030	197,725
4	637,022	491,147
6	7,242,534	312,352
8	1,931,677	13,047
10 and 12	1,799,696	62,574
Over 12*	1,164,379	72,758
20	326,411	43,858

* Excluding 20-in.

The record of pipe installations and retirements in Philadelphia represents probably the best and certainly the longest of any similar record pertaining to an American city of like size.

Acknowledgments

The collection and compilation of the data in Philadelphia were done by personnel under the direction of E. H. Aldrich, Supervising Co-ordinator of the Committee on Survival and Retirement Experience With Water Works Facilities, with the co-operation of the Philadelphia Bureau of Water, of which the late Seth M. Van Loan was Chief, and George S. Levering, head of the distribution subdivision.

TABLE 2

CAUSES OF RETIREMENTS OF CAST-IRON UNLINED MAINS
PHILADELPHIA, PENNSYLVANIA

Size, *in.*	No. of Feet Retired	No. of Feet Abandoned	Percentage of Total	No. of Feet Taken Up	Percentage of Total	Cause of Retirement
3	71,248	29,005	40.7	42,243	59.3	Not given
	125,008	18,507	14.8	106,501	85.2	Replaced
	196,256	47,512	24.2	148,744	75.8	
4	158,418	54,020	34.1	104,398	65.9	Not given
	331,068	36,497	11.0	294,571	89.0	Replaced
	631	538	85.3	93	14.7	Grade crossing
	887	887	100.0	0	0.0	Park construction
	143	0	0.0	143	100.0	Sewer construction
	491,147	91,942	18.7	399,205	81.3	
6	103,922	58,508	56.3	46,414	43.7	Not given
	162,235	41,955	25.9	120,280	74.1	Replaced
	32,221	653	2.0	31,568	98.0	Subway construction
	1,924	1,886	98.0	38	2.0	Street abandoned
	1,787	582	32.6	1,205	67.4	Street changes
	392	367	93.6	25	6.4	Railroad improvements
	1,146	167	14.6	979	85.4	Grade crossing
	379	234	61.7	145	38.3	Sewer construction
	1,382	1,157	83.7	225	16.3	Bridge construction
	2,249	2,249	100.0	0	0.0	Park construction
	4,715	2,878	61.0	1,837	39.0	Miscellaneous
	312,352	109,636	34.5	202,716	65.5	
8	5,444	3,571	65.6	1,873	34.4	Not given
	5,549	1,575	28.4	3,974	71.6	Replaced
	1,464	90	6.1	1,374	93.9	Subway construction
	308	300	97.4	8	2.6	Street changes
	226	226	100.0	0	0.0	Railroad improvements
	56	0	0.0	56	100.0	Grade crossing
	13,047	5,762	44.2	7,285	55.8	
10	7,761	4,278	55.1	3,483	44.9	Not given
	5,521	1,525	27.6	3,996	72.4	Replaced
	2,639	0	0.0	2,639	100.0	Subway construction
	18	18	100.0	0	0.0	Sewer construction
	26	0	0.0	26	100.0	Street change
	277	277	100.0	0	0.0	Railroad improvements
	6	0	0.0	6	100.0	Miscellaneous
	16,248	6,098	37.5	10,150	62.5	

TABLE 2 (contd.)

Size, *in.*	No. of Feet Retired	No. of Feet Abandoned	Percentage of Total	No. of Feet Taken Up	Percentage of Total	Cause of Retirement
12	13,796	5,808	42.1	7,988	57.9	Not given
	21,871	4,942	22.6	16,929	77.4	Replaced
	8,512	0	0.0	8,512	100.0	Subway construction
	1,034	0	0.0	1,034	100.0	Bridge construction
	473	373	78.9	100	21.1	Street changes
	588	588	100.0	0	0.0	Grade crossing
	32	0	0.0	32	100.0	Railroad improvements
	46,306	11,711	25.0	34,595	75.0	
16	699	31	4.4	668	95.6	Not given
	3,359	1,626	48.4	1,733	51.6	Replaced
	18	0	0.0	18	100.0	Subway construction
	4,076	1,657	40.7	2,419	59.3	
20	24,468	3,450	14.1	21,018	85.9	Not given
	6,012	566	9.4	5,446	90.6	Replaced
	6,512	0	0.0	6,512	100.0	Subway construction
	6,866	6,866	100.0	0	0.0	Park construction
	43,858	10,882	24.8	32,976	75.2	
22	1,050	1,050	100.0	0	0.0	Not given
	1,610	0	0.0	1,610	100.0	Replaced
	2,660	1,050	39.5	1,610	60.5	
24	73	0	0	73	100.0	Not given
	73	0	0	73	100.0	
30	38,625	17,985	46.6	20,640	53.4	Not given
	3,394	1,457	42.9	1,937	57.1	Replaced
	71	0	0.0	71	100.0	Subway construction
	799	799	100.0	0	0.0	Park construction
	42,889	20,241	47.2	22,648	52.8	
36	4,464	3,618	81.0	846	19.0	Not given
	229	0	0.0	229	100.0	Replaced
	4,693	3,618	77.1	1,075	22.9	
48	16,312	9,199	56.4	7,113	43.6	Not given
	2,702	1,442	53.4	1,260	46.6	Replaced
	19,014	10,641	56.0	8,373	44.0	
TOTAL	1,192,619	320,750	26.9	871,869	73.1	

TABLE 2 (contd.)

Summary

Size, *in.*	No. of Feet Retired	No. of Feet Abandoned	Percentage of Total	No. of Feet Taken Up	Percentage of Total	Cause of Retirement
All	446,280	189,523	42.5	256,757	57.5	Not given
	668,558	110,092	16.5	558,466	83.5	Replaced
	2,421	1,293	53.4	1,128	46.6	Grade crossing
	10,801	10,801	100.0	0	0	Park construction
	540	252	46.7	288	53.3	Sewer construction
	51,437	743	1.4	50,694	98.6	Subway construction
	1,924	1,886	98.0	38	2.0	Street abandoned
	2,594	1,255	48.3	1,339	51.7	Street change
	927	870	93.9	57	6.1	Railroad improvements
	2,416	1,157	47.9	1,259	52.1	Bridge construction
	4,721	2,878	61.0	1,843	39.0	Miscellaneous
TOTAL	1,192,619	320,750	26.9	871,869	73.1	

TABLE 3

INSTALLATION OF PIPE—DATED BY COMMITTEE
PHILADELPHIA, PENNSYLVANIA

Size, *in.*	No. of Feet Retired	Percentage of Total Retired	No. of Feet in Service	Percentage of Total in Service
3	54,253	27.4	166	1.2
4	102,010	17.3	10,686	7.3
6	17,483	5.6	161,589	2.3
8	91	0.7	6,257	0.3
10	513	3.2	41,017	6.5
12	215	0.5	7,414	0.7
TOTAL	174,565	16.2	227,129	2.1

Summary of Installations and Retirements Philadelphia, Pennsylvania

MAINS

3-in. Cast-Iron Unlined Mains

Year Installed	*Feet Installed*	*Feet In Service*	*Feet Retired*
1822	851	0	851
1823	430	0	430
1824	3,542	0	3,542
1825	2,793	0	2,793
1826	8,783	446	8,337
1827	18,280	317	17,963
1828	10,371	336	10,035
1829	2,974	188	2,786
1830	28,164	1,009	27,155
1831	7,852	358	7,494
1832	5,194	365	4,829
1833	4,666	207	4,459
1834	1,631	396	1,235
1835	9,088	264	8,824
1836	6,131	0	6,131
1837	5,132	0	5,132
1838	2,872	221	2,651
1839	2,886	11	2,875
1840	12,062	1,259	10,803
1841	2,131	0	2,131
1842	1,459	365	1,094
1843	894	258	636
1844	1,518	206	1,312
1845	4,289	225	4,064
1846	4,020	265	3,755
1847	1,508	75	1,433
1848	4,439	87	4,352
1849	7,646	410	7,236
1850	7,501	0	7,501
1851	1,654	110	1,544
1852	5,102	0	5,102
1853	2,608	0	2,608
1854	27	0	27
1855	4,935	423	4,512
1856	3,881	0	3,881
1857	2,421	97	2,324
1858	1,548	0	1,548
1859	692	241	451
1860	2,495	278	2,217
1861	2,739	274	2,465
1862	658	322	336
1863	894	774	120
1865	875	0	875
1866	992	780	212
1868	1,927	527	1,400
1869	1,359	135	1,224
1870	487	0	487
1871	167	167	0
1873	591	0	591
1874	1,481	0	1,481
1876	59	0	59
1881	68	0	68
1883	18	0	18
1886	450	450	0
1889	264	0	264
1892	446	0	446
1893	1,410	50	1,360
1894	316	50	266
1895	50	50	0
1900	78	78	0
1920	491	491	0
1925	469	469	0
1932	908	908	0
1936	363	363	0
1940	0	0	0
Total	212,030	14,305	197,725

Retirements by Years

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1822	401	1885	450	1887		
1823	140	1885	290	1886		
1824	3,042	1885	108	1891	250	1893
	142	1895				
1825	734	1877	44	1880	146	1885
	76	1886	87	1892	39	1893
	664	1894	635	1895	170	1899
	198	1900				
1826	666	1876	896	1880	49	1884
	2,538	1885	566	1888	1,161	1889
	25	1890	253	1892	419	1893
	613	1894	155	1895	603	1896
	382	1899	11	1900		
1827	192	1827	1,419	1846	658	1877
	675	1879	654	1873	1,029	1884
	6,596	1885	3,106	1886	644	1888

3-IN. CAST-IRON UNLINED MAINS (contd.)

Retirements by Years (contd.)

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1827	350	1889	29	1890	807	1891
	308	1892	151	1893	445	1894
	633	1896	247	1928	20	1930
1828	346	1880	2,384	1885	465	1886
	8	1887	333	1888	862	1889
	447	1891	836	1892	1,730	1893
	1,123	1894	15	1895	807	1896
	170	1897	466	1898	43	1915
1829	418	1886	27	1892	515	1893
	796	1894	226	1896	264	1902
	512	1904	28	1905		
1830	1,225	1866	6,125	1872	2,869	1876
	225	1877	722	1879	183	1883
	1,411	1885	3,212	1886	829	1887
	966	1888	182	1889	1,419	1890
	964	1892	1,924	1893	621	1894
	382	1896	134	1898	790	1899
	2,780	1904	154	1906	38	1918
1831	289	1879	190	1883	459	1885
	1,666	1886	17	1887	949	1888
	284	1891	592	1892	976	1893
	350	1894	355	1895	152	1896
	437	1897	27	1898	153	1900
	222	1919	376	1926		
1832	298	1879	162	1880	421	1883
	26	1887	400	1889	23	1891
	20	1892	1,000	1893	458	1894
	10	1895	534	1896	236	1897
	797	1898	175	1899	94	1900
	175	1924				
1833	1,488	1885	458	1886	446	1889
	223	1892	388	1893	33	1894
	179	1896	1,025	1897	219	1912
1834	269	1883	152	1886	451	1891
	283	1892	80	1893		
1835	832	1885	2,575	1886	450	1888
	31	1890	441	1891	528	1892
	651	1893	1,074	1894	507	1895
	1,519	1896	216	1897		
1836	74	1886	28	1892	493	1893
	1,566	1894	901	1895	396	1896
	90	1898	1,314	1899	797	1900
	172	1902	300	1932		
1837	939	1885	390	1886	16	1887
	28	1890	435	1891	261	1892
	804	1893	57	1894	870	1896
	252	1897	869	1899	211	1932
1838	564	1892	165	1893	447	1894
	416	1895	469	1896	590	1899
1839	34	1886	392	1889	448	1890
	477	1892	489	1893	263	1894
	629	1896	143	1902		
1840	1,300	1868	2,632	1873	53	1884
	182	1886	438	1888		
	1,587	1890	712	1892	795	1893
	54	1894	1,015	1896	479	1897
	290	1898	198	1899	456	1903
	102	1906	510	1930		
1841	180	1846	184	1879	214	1885
	339	1886	768	1888	57	1893
	389	1896				
1842	456	1888	236	1891	29	1892
	123	1893	39	1894	112	1895
	99	1900				
1843	25	1890	19	1892	542	1896
	50	1899				
1844	500	1886	56	1889	258	1893
	54	1894	243	1896	201	1897
1845	270	1885	20	1886	120	1888
	227	1889	1,021	1891	1,689	1893
	30	1894	396	1896	135	1897
	156	1899				
1846	135	1881	455	1884	200	1886
	450	1888	29	1889	410	1890
	9	1891	483	1892	499	1893
	28	1894	548	1896	509	1900
1847	43	1892	443	1893	54	1894
	398	1898	396	1899	99	1900
1848	450	1878	1,612	1886	778	1888
	210	1893	24	1894	142	1895
	19	1898	606	1899	219	1901
	292	1905				
1849	422	1849	306	1877	588	1885
	899	1886	394	1890	590	1891
	314	1892	363	1893	54	1894
	418	1895	422	1896	1,942	1899
	396	1900	128	1902		
1850	721	1868	1,424	1885	884	1886
	146	1891	21	1892	3,282	1893
	27	1894	286	1895	164	1899
	546	1900				
1851	285	1886	12	1890	445	1893
	98	1894	308	1896	396	1899
1852	399	1886	23	1888	84	1889
	22	1890	51	1892	547	1893
	758	1894	556	1896	396	1897
	2,019	1899	247	1900		
1853	447	1886	119	1888	258	1890
	508	1893	399	1894	73	1896
	522	1899	282	1900		
1854	27	1893				
1855	1,565	1886	31	1889	341	1891
	27	1892	493	1893	84	1894
	788	1896	584	1897	203	1898
	396	1900				

3-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years (contd.)

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1856	344	1856	261	1879	27	1888
	419	1890	26	1891	868	1892
	786	1893	158	1894	992	1899
1857	371	1857	28	1886	28	1888
	28	1891	544	1892	242	1893
	205	1902	322	1919	556	1931
1858	19	1888	54	1894	765	1895
	154	1896	556	1897		
1859	49	1894	24	1896	32	1898
	78	1902	267	1904		
1860	737	1886	84	1889	86	1893
	372	1899	494	1900	355	1904
	89	1923				
1861	25	1861	32	1886	16	1887
	27	1888	428	1889	1,022	1892
	62	1894	20	1895	24	1898
	200	1899	342	1900	267	1903

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1862	336	1886				
1863	120	1898				
1865	657	1885	23	1886	195	1899
1866	185	1868	27	1895		
1868	1,300	1873	100	1877		
1869	424	1888	778	1893	22	1894
1870	60	1890	35	1891	363	1893
	29	1894				
1873	566	1873	25	1892		
1874	462	1874	716	1885	303	1888
1876	28	1885	31	1893		
1881	68	1889				
1883	18	1931				
1889	264	1903				
1892	446	1892				
1893	1,360	1897				
1894	266	1896				

4-in. Cast-Iron Unlined Mains

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1823	275	275	0
1824	1,352	0	1,352
1825	527	0	527
1826	5,962	0	5,962
1827	8,740	1,624	7,116
1828	2,701	1,645	1,056
1829	4,426	0	4,426
1830	13,861	620	13,241
1831	657	0	657
1832	3,100	1,232	1,868
1833	3,483	382	3,101
1834	1,610	1,274	336
1835	8,210	1,231	6,979
1836	3,334	0	3,334
1837	3,973	2,838	1,135
1838	5,542	0	5,542
1839	3,247	309	2,938
1840	24,899	2,320	22,579
1841	2,786	0	2,786
1842	5,534	975	4,559
1843	6,019	51	5,968
1844	1,732	446	1,286
1845	12,286	2,041	10,245
1846	649	24	625
1847	520	444	76
1848	72	0	72
1849	1,388	41	1,347
1850	13,565	300	13,265
1851	5,841	1,031	4,810
1852	18,219	3,350	14,869

Year	*Feet*		
Installed	*Installed*	*In Service*	*Retired*
1853	15,852	2,488	13,364
1854	5,014	371	4,643
1855	9,437	752	8,685
1856	19,226	1,214	18,012
1857	21,041	0	21,041
1858	25,335	2,184	23,151
1859	25,238	4,176	21,062
1860	32,602	4,676	27,926
1861	14,091	1,823	12,268
1862	8,245	1,387	6,858
1863	14,732	6,316	8,416
1864	11,222	0	11,222
1865	11,556	246	11,310
1866	9,729	1,022	8,707
1867	12,034	1,796	10,238
1868	12,483	1,548	10,935
1869	15,265	1,049	14,216
1870	31,992	2,754	29,238
1871	26,376	3,974	22,402
1872	29,544	3,332	26,212
1873	28,464	4,859	23,605
1874	3,610	1,461	2,149
1875	1,127	290	837
1876	1,782	748	1,034
1878	5,595	626	4,969
1880	1,730	918	812
1881	233	233	0
1882	13	0	13
1883	56	56	0
1885	286	0	286

4-in. Cast-Iron Unlined Mains (contd.)

Year Installed	Feet Installed	Feet In Service	Feet Retired
1886	151	79	72
1887	305	276	29
1889	57	0	57
1894	5,272	4,922	350
1895	42	12	30
1897	722	246	476
1898	163	0	163
1899	770	612	158
1900	147	147	0
1902	28	28	0
1904	5,386	5,366	20
1905	978	978	0
1906	1,679	166	1,513
1907	27	27	0
1908	1,130	180	950
1910	771	20	751
1911	1,525	1,010	515
1917	20	20	0
1919	23	23	0
1921	1,229	1,229	0
1922	389	389	0
1924	975	975	0
1926	315	315	0
1927	9,640	9,245	395
1928	30,834	30,834	0
1929	14,164	14,164	0
1930	1,204	1,204	0
1932	4	4	0
1933	4	4	0
1934	31	31	0
1935	20	20	0
1936	220	220	0
1940	377	377	0
Total	637,022	145,875	491,147

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1824	475	1878	481	1885	396	1886
1825	527	1892				
1826	288	1877	50	1878	2,987	1885
	672	1886	50	1888	168	1890
	1,457	1891	290	1893		
1827	343	1877	1,280	1885	417	1886
	32	1889	25	1890	40	1891
	478	1892	400	1893	995	1894
	1,334	1895	446	1896	788	1899
	155	1900	383	1901		
1828	321	1885	146	1890	22	1892
	16	1894	200	1897	96	1898
	40	1900	10	1904	33	1915
	172	1935				
1829	300	1858	1,208	1887	308	1892
	100	1893	2,510	1894		
1830	2,999	1875	920	1876	452	1886
	10	1887	27	1888	776	1889
	588	1892	1,073	1893	1,962	1894
	574	1895	423	1896	497	1897
	230	1898	1,878	1899	391	1900
	216	1901	225	1920		
1831	43	1892	28	1893	50	1894
	476	1900	60	1903		
1832	376	1889	19	1891	62	1892
	1,236	1893	28	1894	147	1903
1833	1,416	1886	5	1888	306	1891
	908	1892	33	1894	433	1930
1834	20	1893	88	1894	228	1901
1835	200	1870	75	1875	516	1885
	35	1886	29	1889	500	1891
	933	1892	1,587	1893	77	1894
	1,058	1895	363	1896	397	1897
	817	1899	392	1928		
1836	420	1891	1,561	1893	1,353	1894
1837	45	1871	404	1889	153	1893
	389	1900	144	1904		
1838	35	1889	552	1892	1,071	1893
	415	1894	1,799	1899	230	1901
	1,440	1906				
1839	526	1889	250	1892	951	1893
	415	1894	399	1895	397	1901
1840	341	1860	7,865	1871	28	1888
	167	1889	912	1891	1,595	1892
	1,654	1893	1,792	1894	208	1895
	2,571	1896	322	1897	432	1898
	2,429	1899	346	1901	480	1902
	444	1908	143	1913	850	1918
1841	883	1885	41	1890	34	1894
	124	1896	256	1897	1,179	1899
	269	1900				
1842	45	1872	23	1891	404	1892
	1,152	1893	50	1894	929	1896
	308	1897	798	1899	850	1900
1843	30	1874	438	1888	448	1893
	212	1894	1,286	1896	537	1898
	1,836	1899	381	1900	642	1901
	158	1902				
1844	910	1885	347	1893	29	1894
1845	758	1871	532	1880	721	1886
	149	1888	469	1889	984	1892
	2,223	1893	1,050	1894	1,044	1896
	395	1897	1,920	1899		
1846	396	1896	229	1900		
1847	34	1886	42	1896		
1848	72	1886				
1849	33	1887	40	1890	1,097	1892
	129	1896	48	1898		

4-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years (contd.)

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1850	372	1880	254	1885	1,744	1886
	59	1888	534	1889	630	1891
	466	1892	835	1893	1,821	1894
	51	1895	1,315	1896	2,835	1899
	586	1900	838	1901	925	1902
1851	90	1881	362	1886	47	1887
	2,300	1888	403	1889	1,068	1892
	85	1894	455	1896		
1852	445	1881	32	1885	1,022	1886
	261	1891	6,096	1893	977	1894
	19	1895	972	1896	734	1897
	1,070	1899	536	1900	34	1901
	848	1902	60	1904	353	1905
	666	1908	266	1909	478	1914
1853	170	1885	819	1888	99	1890
	1,292	1891	16	1892	1,825	1893
	637	1894	392	1895	3,624	1896
	612	1898	793	1899	521	1900
	66	1902	1,162	1903	105	1911
	1,231	1913				
1854	220	1885	40	1891	27	1892
	180	1893	1,228	1894	845	1896
	1,376	1897	440	1899	287	1902
1855	52	1888	33	1890	515	1891
	360	1892	710	1893	651	1894
	541	1895	852	1896	317	1897
	1,470	1898	1,398	1899	224	1900
	186	1902	400	1904	323	1908
	653	1909				
1856	1,435	1886	1,391	1887	1,378	1888
	471	1890	436	1891	936	1892
	771	1893	7,744	1894	783	1895
	920	1896	352	1898	557	1899
	418	1901	420	1903		
1857	174	1859	37	1878	440	1880
	1,055	1885	1,298	1886	27	1888
	55	1889	329	1891	5,480	1892
	1,373	1893	1,544	1894	1,180	1895
	2,782	1896	876	1897	632	1898
	1,952	1899	839	1900	420	1904
	364	1908	184	1924		
1858	27	1858	338	1886	869	1889
	70	1890	30	1891	1,326	1892
	3,447	1893	3,666	1894	396	1895
	4,606	1896	992	1897	3,764	1899
	1,380	1900	359	1901	38	1911
	968	1918	518	1919	357	1921
1859	564	1867	174	1878	1,358	1886
	201	1889	100	1890	374	1891
	712	1892	1,767	1893	2,028	1894

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1859	396	1895	413	1896	1,579	1897
	1,298	1898	5,980	1899	869	1900
	810	1901	408	1902	1,694	1905
	307	1909	30	1919		
1860	396	1860	410	1879	972	1886
	12	1887	540	1888	85	1889
	593	1890	466	1891	1,307	1892
	2,127	1893	3,120	1894	1,205	1895
	2,978	1896	1,394	1897	2,273	1898
	4,994	1899	1,275	1900	1,046	1901
	485	1903	366	1904	389	1905
	498	1908	320	1909	272	1913
	203	1920	170	1928	30	1930
1861	61	1861	450	1886	25	1888
	27	1889	424	1891	2,848	1892
	1,547	1893	849	1894	558	1897
	2,559	1899	500	1900	257	1902
	105	1903	398	1904	16	1906
	438	1907	383	1909	152	1911
	343	1913	328	1916		
1862	31	1862	24	1888	46	1890
	43	1891	327	1892	594	1893
	426	1894	72	1895	1,203	1896
	1,833	1897	504	1898	52	1901
	709	1902	349	1906	374	1908
	271	1926				
1863	185	1864	165	1865	1,511	1886
	28	1889	50	1892	2,244	1893
	292	1894	2,201	1897	352	1899
	1,114	1900	274	1902		
1864	1,102	1864	83	1869	4	1887
	47	1890	339	1892	1,134	1893
	610	1894	1,146	1895	644	1896
	813	1897	559	1899	1,438	1900
	960	1901	603	1902	1,024	1903
	696	1910	20	1913		
1865	2,428	1886	89	1889	77	1890
	524	1891	28	1892	2,299	1893
	179	1894	76	1895	896	1896
	910	1897	1,000	1899	910	1900
	681	1901	288	1905	23	1906
	902	1908				
1866	27	1866	487	1871	66	1889
	900	1890	83	1891	455	1892
	1,890	1893	246	1894	45	1895
	325	1896	1,076	1897	548	1898
	820	1899	947	1900	291	1903
	408	1917	93	1918		
1867	1,905	1871	988	1885	453	1887
	456	1888	970	1890	250	1891

4-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years (contd.)

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1867	1,721	1893	185	1894	814	1895
	719	1896	611	1897	43	1906
	777	1908	346	1909		
1868	38	1868	1,137	1889	42	1890
	875	1893	853	1894	1,302	1895
	1,339	1897	1,748	1898	1,451	1899
	802	1900	50	1909	1,298	1910
1869	422	1869	395	1877	54	1886
	30	1889	82	1890	514	1891
	56	1892	2,179	1893	533	1894
	1,500	1895	2,576	1896	1,437	1897
	1,047	1898	2,105	1899	393	1900
	25	1901	425	1902	443	1905
1870	13	1884	545	1886	16	1887
	27	1888	949	1889	1,087	1890
	374	1891	462	1892	836	1893
	1,657	1894	847	1895	4,953	1896
	3,805	1897	5,450	1898	2,777	1899
	2,387	1900	393	1901	750	1902
	300	1903	190	1905	349	1908
	312	1913	378	1915	381	1931
1871	689	1875	54	1882	206	1886
	229	1887	27	1888	140	1890
	416	1891	104	1892	3,587	1893
	992	1894	3,665	1895	245	1897
	3,485	1898	3,221	1899	761	1900
	100	1901	451	1902	359	1905
	26	1906	87	1907	791	1908
	918	1909	12	1911	1,125	1913
	136	1930	576	1932		
1872	233	1872	8	1887	28	1890
	555	1891	178	1892	722	1893
	2,074	1894	659	1895	3,434	1896
	1,752	1897	3,451	1898	4,158	1899
	399	1900	1,511	1901	823	1902
	50	1903	575	1904	1,822	1905

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1872	836	1908	1,073	1909	28	1912
	885	1913	494	1925	464	1930
1873	4	1887	593	1890	1,185	1891
	1,125	1892	230	1893	593	1894
	635	1895	1,754	1896	3,676	1897
	4,097	1898	2,122	1899	773	1900
	1,502	1901	383	1902	607	1903
	446	1904	471	1905	456	1906
	717	1908	1,582	1909	400	1926
	254	1930				
1874	679	1893	25	1894	32	1895
	35	1896	303	1900	230	1902
	656	1909	189	1913		
1875	112	1875	75	1891	650	1899
1876	176	1880	82	1887	350	1892
	52	1893	27	1894	347	1931
1878	1,984	1890	25	1892	50	1894
	395	1898	2,515	1899		
1880	812	1902				
1882	13	1895				
1885	194	1899	92	1914		
1886	72	1888				
1887	29	1893				
1889	57	1889				
1894	35	1894	15	1896	85	1922
	215	1931				
1895	30	1912				
1897	450	1897	26	1911		
1898	163	1900				
1899	79	1925	79	1926		
1904	20	1915				
1906	28	1908	137	1912	1,348	1931
1908	950	1926				
1910	263	1912	488	1932		
1911	10	1912	505	1926		
1927	395	1928				

4½-in. Cast-Iron Unlined Mains

Year Installed	*Feet* *Installed*	*In Service*	*Retired*
1817	430	0	430
1940	0	0	0
Total	430	0	430

Retirements by Years

Year Installed	*Feet*	*Year*
1817	430	1915

6-IN. CAST-IRON UNLINED MAINS

Year Installed	Feet Installed	Feet In Service	Feet Retired	Year Installed	Feet Installed	Feet In Service	Feet Retired
1821	1,921	1,921	0	1876	98,286	93,568	4,718
1822	12,997	1,752	11,245	1877	70,343	69,118	1,225
1823	4,836	3,985	851	1878	43,730	41,956	1,774
1824	8,926	8,870	56	1879	19,460	18,207	1,253
1826	15,627	15,523	104	1880	23,441	21,678	1,763
1827	30,979	28,104	2,875	1881	28,418	26,700	1,718
1828	20,812	18,529	2,283	1882	32,274	27,644	4,630
1829	15,023	13,384	1,639	1883	42,464	41,889	575
1830	24,831	19,548	5,283	1884	49,364	45,254	4,110
1831	8,920	5,535	3,385	1885	122,331	116,502	5,829
1832	15,162	14,631	531	1886	119,141	113,168	5,973
1833	16,617	14,543	2,074	1887	77,535	73,444	4,091
1834	16,653	10,919	5,734	1888	121,759	118,421	3,338
1835	39,059	33,747	5,312	1889	124,452	119,277	5,175
1836	15,022	11,779	3,243	1890	147,507	143,978	3,529
1837	12,306	9,014	3,292	1891	170,840	167,155	3,685
1838	17,014	13,931	3,083	1892	153,360	148,394	4,966
1839	16,734	15,133	1,601	1893	208,046	199,696	8,350
1840	25,177	24,282	895	1894	200,516	192,510	8,006
1841	7,210	7,201	9	1895	174,930	171,659	3,271
1842	5,764	4,989	775	1896	159,492	152,681	6,811
1843	3,826	2,511	1,315	1897	153,452	151,741	1,711
1844	10,812	8,697	2,115	1898	146,869	143,294	3,575
1845	22,652	20,200	2,452	1899	147,909	143,402	4,507
1846	12,385	11,334	1,051	1900	104,083	100,864	3,219
1847	5,505	5,472	33	1901	95,862	94,072	1,790
1848	12,388	10,759	1,629	1902	94,258	90,228	4,030
1849	5,240	4,780	460	1903	61,822	61,195	627
1850	29,013	27,693	1,320	1904	63,936	63,372	564
1851	5,660	4,959	701	1905	122,732	120,293	2,439
1852	33,332	29,788	3,544	1906	121,860	121,131	729
1853	27,118	25,247	1,871	1907	113,072	111,727	1,345
1854	11,980	9,588	2,392	1908	115,271	113,706	1,565
1855	33,624	31,952	1,672	1909	109,001	107,236	1,765
1856	40,672	35,648	5,024	1910	101,288	99,922	1,366
1857	38,072	35,535	2,537	1911	74,090	73,124	966
1858	46,619	43,059	3,560	1912	57,664	57,043	621
1859	51,943	47,269	4,674	1913	43,198	43,198	0
1860	81,675	75,239	6,436	1914	56,031	55,686	345
1861	40,848	31,659	9,189	1915	65,851	64,933	918
1862	32,322	26,357	5,965	1916	42,896	42,864	32
1863	38,301	35,346	2,955	1917	43,744	43,679	65
1864	23,805	20,764	3,041	1918	25,303	24,398	905
1865	30,507	27,941	2,566	1919	38,433	35,180	3,253
1866	27,785	24,213	3,572	1920	25,180	25,160	20
1867	58,792	49,421	9,371	1921	31,822	31,455	367
1868	52,953	49,850	3,103	1922	70,730	70,730	0
1869	79,710	61,745	17,965	1923	72,173	72,105	68
1870	86,069	81,656	4,413	1924	96,756	96,681	75
1871	102,259	96,012	6,247	1925	150,701	150,481	220
1872	99,149	93,980	5,169	1926	141,621	141,591	30
1873	143,962	137,866	6,096	1927	124,615	124,103	512
1874	182,405	175,224	7,181	1928	130,539	129,716	823
1875	141,325	137,703	3,622	1929	99,370	97,781	1,589

6-in. Cast-Iron Unlined Mains (contd.)

Year Installed	Feet Installed	Feet In Service	Feet Retired
1930	49,720	49,710	10
1931	42,195	42,195	0
1932	5,802	5,802	0
1933	5,276	5,276	0
1934	5,057	5,057	0
1935	4,529	4,529	0
1936	9,460	9,460	0
1937	7,889	7,889	0
1938	9,166	9,166	0
1939	17,349	17,349	0
1940	11,972	11,972	0
Total	7,242,534	6,930,182	312,352

6-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1822	5	1877	452	1885	60	1905
	2,485	1907	8,243	1908		
1823	851	1908				
1824	56	1908				
1826	36	1901	48	1908	20	1926
1827	350	1846	17	1890	339	1893
	15	1912	40	1915	22	1918
	78	1924	657	1926	446	1928
	59	1929	852	1930		
1828	630	1879	520	1894	253	1896
	48	1919	396	1932	436	1935
1829	396	1896	24	1901	445	1910
	650	1925	124	1931		
1830	694	1859	390	1888	360	1896
	84	1899	32	1912	40	1915
	75	1919	2,425	1925	505	1926
	67	1930	160	1931	157	1932
	294	1934				
1831	897	1885	28	1888	25	1894
	678	1919	230	1924	330	1925
	52	1931	1,145	1932		
1832	54	1886	468	1925	9	1931
1833	100	1898	165	1899	43	1905
	127	1918	505	1925	1,124	1930
	10	1932				
1834	731	1899	966	1904	2,230	1905
	608	1906	473	1911	525	1925
	189	1931	12	1932		
1835	453	1874	4	1887	226	1889
	45	1890	353	1894	166	1895
	37	1902	872	1904	1,014	1905
	19	1908	578	1915	524	1925
	58	1929	155	1931	808	1932
1836	1,824	1886	22	1893	32	1894
	100	1898	797	1901	246	1902
	85	1919	60	1921	19	1929
	8	1932	50	1936		
1837	555	1891	562	1902	54	1904
	767	1922	1,200	1925	154	1931
1838	375	1859	80	1893	801	1895
	75	1904	132	1915	1,362	1925
	11	1931	247	1932		
1839	192	1902	357	1904	182	1907
	821	1918	49	1931		
1840	168	1891	89	1892	97	1893
	495	1911	36	1926	10	1931
1841	9	1876				
1842	108	1872	276	1883	72	1891
	319	1901				
1843	320	1859	20	1894	400	1899
	350	1907	225	1931		
1844	1,450	1891	526	1894	18	1911
	121	1932				
1845	33	1866	123	1898	480	1902
	85	1903	752	1904	938	1911
	41	1925				
1846	186	1899	27	1901	51	1908
	450	1918	321	1922	16	1930
1847	33	1866				
1848	54	1908	82	1911	125	1917
	452	1919	9	1925	555	1930
	238	1931	114	1932		
1849	72	1929	388	1930		
1850	663	1890	205	1893	82	1894
	360	1898	10	1899		
1851	281	1911	28	1912	392	1932
1852	2,572	1890	526	1894	134	1897
	217	1904	2	1913	58	1921
	10	1925	25	1930		
1853	740	1866	35	1889	520	1896
	64	1927	54	1929	458	1930
1854	1,465	1890	184	1891	550	1895
	40	1902	25	1904	128	1929
1855	230	1859	300	1866	20	1892
	65	1893	117	1894	85	1898
	554	1906	25	1925	56	1926
	15	1931	205	1932		
1856	685	1858	173	1859	296	1866
	60	1875	498	1876	268	1885
	5	1886	492	1901	1,506	1904
	324	1906	717	1932		
1857	564	1875	136	1894	20	1905
	918	1918	56	1922	21	1925
	467	1930	200	1931	155	1934

6-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years (contd.)

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1858	250	1859	232	1863	218	1864
	193	1882	81	1886	753	1892
	420	1893	14	1894	15	1898
	392	1899	155	1902	228	1915
	493	1921	91	1925	25	1930
1859	219	1860	339	1861	400	1863
	1,216	1890	25	1891	17	1892
	32	1893	37	1894	376	1898
	1,177	1911	150	1915	394	1917
	10	1924	253	1925	29	1931
1860	425	1861	177	1863	34	1887
	41	1888	433	1889	433	1890
	317	1892	120	1893	545	1894
	34	1896	84	1898	855	1900
	477	1902	59	1907	77	1911
	45	1915	140	1918	12	1927
	50	1929	1,321	1931	657	1932
	100	1938				
1861	386	1864	398	1869	294	1876
	76	1877	1,172	1890	223	1891
	144	1892	637	1893	32	1894
	20	1898	669	1899	1,134	1900
	2,759	1901	198	1902	438	1904
	384	1926	225	1928		
1862	453	1886	10	1888	1,460	1898
	1,418	1899	521	1916	2,019	1925
	84	1931				
1863	400	1864	385	1877	567	1891
	137	1893	425	1899	384	1901
	20	1921	609	1925	16	1926
	12	1930				
1864	270	1875	356	1876	2,312	1886
	41	1893	25	1894	37	1902
1865	867	1886	986	1890	47	1894
	343	1899	271	1904	22	1925
	30	1928				
1866	550	1867	291	1886	143	1890
	275	1891	236	1899	60	1904
	443	1909	1,118	1925	390	1930
	66	1932				
1867	1,549	1877	629	1893	465	1894
	13	1905	791	1909	5,918	1925
	6	1926				
1869	658	1868	72	1882	16	1892
	12	1897	1,612	1900	76	1911
	532	1930	104	1931	21	1935
1869	58	1884	261	1893	127	1896
	498	1902	3,549	1904	1,002	1905
	24	1906	242	1907	33	1908
	149	1910	455	1912	719	1913
	15	1921	4,563	1922	45	1923
	13	1924	1,589	1930	4,623	1931

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1870	550	1872	400	1873	765	1890
	256	1891	379	1894	15	1899
	19	1903	28	1906	46	1911
	131	1912	226	1913	588	1914
	500	1915	510	1930		
1871	446	1871	559	1877	1,987	1883
	724	1893	24	1894	349	1904
	80	1913	96	1915	84	1921
	1,650	1925	248	1930		
1872	454	1873	14	1885	235	1889
	1,061	1890	61	1891	22	1893
	655	1899	548	1901	57	1904
	552	1906	366	1913	400	1914
	230	1916	17	1926	69	1927
	313	1930	115	1932		
1873	180	1875	123	1876	108	1877
	24	1885	97	1887	256	1888
	2	1892	22	1899	31	1900
	1,235	1903	355	1904	13	1907
	48	1910	271	1918	48	1921
	599	1924	550	1925	16	1927
	1,499	1930	114	1932	505	1937
1874	48	1881	240	1883	164	1887
	277	1889	7	1890	714	1891
	247	1892	56	1894	27	1896
	60	1900	768	1904	218	1905
	14	1906	15	1907	466	1909
	550	1918	110	1921	362	1925
	217	1926	147	1929	176	1930
	1,556	1931	742	1932		
1875	641	1877	32	1885	105	1892
	36	1894	221	1901	113	1903
	463	1905	41	1909	382	1918
	10	1921	114	1925	741	1926
	706	1930	17	1932		
1876	52	1878	55	1884	494	1886
	30	1889	36	1890	115	1900
	735	1903	476	1906	522	1908
	134	1917	53	1920	221	1921
	192	1922	1,138	1925	28	1931
	88	1932	349	1939		
1877	29	1893	323	1908	20	1920
	646	1926	188	1929	19	1932
1878	11	1884	81	1887	10	1890
	55	1899	109	1907	36	1912
	245	1915	408	1926	424	1930
	227	1932	168	1933		
1879	235	1892	35	1896	50	1903
	274	1927	182	1929	477	1932
1880	19	1892	26	1904	392	1905
	768	1906	5	1911	250	1919
	92	1930	155	1931	56	1939

6-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years (contd.)

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1881	273	1883	300	1908	356	1910
	37	1913	752	1930		
1882	252	1886	72	1893	2,614	1904
	71	1908	70	1912	320	1915
	236	1918	295	1931	451	1932
	249	1939				
1883	12	1891	25	1894	43	1898
	27	1901	242	1907	31	1926
	3	1927	30	1929	42	1931
	120	1932				
1884	170	1884	1,912	1894	121	1895
	601	1902	103	1908	381	1911
	203	1913	537	1916	17	1925
	65	1933				
1885	45	1887	26	1892	20	1896
	60	1902	136	1903	375	1908
	252	1910	254	1911	147	1913
	127	1915	989	1924	1,306	1925
	146	1926	581	1929	209	1931
	469	1932	4	1933	683	1939
1886	34	1886	12	1888	45	1893
	146	1898	11	1905	371	1910
	141	1914	355	1915	97	1916
	299	1918	45	1919	1,407	1920
	81	1921	86	1925	791	1927
	895	1928	18	1929	399	1930
	240	1931	309	1933	191	1934
1887	8	1887	204	1894	76	1896
	330	1897	282	1898	35	1902
	28	1903	120	1905	32	1909
	35	1914	1,020	1915	102	1921
	801	1924	10	1925	136	1927
	52	1932	267	1934	553	1935
1888	76	1890	175	1893	234	1896
	10	1899	27	1901	33	1903
	25	1905	31	1906	21	1907
	300	1910	212	1916	53	1917
	30	1919	29	1927	142	1928
	7	1931	1,472	1932	30	1935
	431	1939				
1889	15	1892	143	1894	8	1896
	1,080	1898	633	1903	1,006	1908
	18	1909	28	1911	97	1914
	700	1915	113	1923	42	1925
	58	1926	50	1929	273	1930
	450	1931	9	1932	452	1933
1890	12	1891	262	1894	30	1900
	240	1901	1,860	1902	82	1909
	25	1910	38	1911	28	1914
	250	1915	73	1918	80	1922

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1890	40	1925	218	1926	18	1930
	252	1932	21	1939		
1891	56	1891	20	1892	346	1894
	220	1896	37	1900	51	1902
	610	1903	64	1904	59	1906
	13	1908	115	1909	150	1911
	27	1913	50	1915	225	1918
	21	1920	895	1926	9	1928
	184	1930	463	1931	35	1932
	35	1934				
1892	287	1892	85	1893	50	1895
	202	1896	50	1897	55	1898
	202	1900	84	1901	28	1902
	350	1903	80	1904	125	1909
	12	1911	69	1912	13	1913
	172	1914	238	1915	962	1916
	248	1918	25	1923	36	1924
	710	1925	9	1927	170	1929
	232	1930	60	1931	51	1932
	309	1934	52	1939		
1893	157	1893	50	1894	50	1895
	32	1897	36	1898	439	1899
	20	1901	64	1902	24	1903
	50	1908	287	1909	620	1910
	74	1911	738	1912	404	1913
	168	1915	240	1916	160	1918
	269	1919	25	1920	447	1921
	440	1923	1,134	1925	157	1926
	269	1929	65	1930	99	1931
	1,784	1932	13	1933	35	1935
1894	769	1894	60	1895	779	1896
	425	1897	260	1898	457	1899
	229	1900	110	1901	107	1903
	229	1904	129	1905	24	1906
	106	1907	205	1908	91	1909
	40	1910	456	1911	88	1912
	109	1913	523	1915	42	1916
	26	1917	331	1918	44	1921
	26	1923	893	1925	140	1926
	14	1927	36	1929	100	1930
	869	1931	157	1933	132	1935
1895	50	1896	62	1898	25	1899
	219	1901	175	1903	30	1904
	29	1907	60	1908	25	1910
	80	1911	138	1912	475	1917
	160	1918	377	1919	55	1920
	36	1921	26	1924	20	1925
	131	1926	96	1929	479	1930
	167	1932	356	1935		
1896	84	1896	50	1898	84	1900

6-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years (contd.)

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1896	85	1901	75	1902	268	1903
	91	1904	75	1905	40	1906
	12	1908	91	1909	201	1910
	132	1911	100	1912	28	1913
	8	1914	47	1915	178	1916
	22	1917	150	1918	15	1920
	169	1921	31	1922	20	1925
	779	1926	265	1928	977	1929
	425	1930	1,000	1931	785	1932
	401	1933	63	1935		
1897	50	1897	113	1898	50	1899
	100	1901	46	1906	26	1907
	25	1908	50	1915	50	1918
	450	1920	46	1925	124	1928
	8	1929	83	1930	47	1931
	161	1932	282	1933		
1898	118	1900	43	1901	23	1905
	29	1906	27	1907	25	1909
	40	1910	149	1911	212	1913
	14	1915	35	1916	111	1918
	5	1919	26	1920	1,986	1925
	621	1926	42	1928	5	1932
	25	1933	39	1940		
1899	85	1899	30	1901	32	1903
	55	1907	30	1908	80	1909
	426	1910	266	1912	14	1913
	704	1915	111	1916	183	1917
	481	1918	38	1919	20	1920
	558	1922	38	1929	710	1930
	65	1931	6	1932	575	1935
1900	180	1900	25	1901	25	1902
	190	1904	520	1906	119	1908
	27	1911	50	1915	131	1916
	61	1917	128	1918	50	1920
	252	1923	78	1924	126	1929
	972	1930	249	1931	36	1932
1901	57	1901	361	1903	53	1905
	30	1906	55	1907	219	1910
	100	1911	438	1913	55	1914
	8	1919	75	1924	100	1929
	239	1930				
1902	30	1903	50	1905	129	1908
	50	1909	711	1912	62	1917
	2,852	1926	11	1927	3	1931
	107	1932	25	1935		
1903	13	1904	130	1905	2	1906
	3	1909	44	1910	190	1911
	69	1913	5	1918	39	1919

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1903	78	1924	54	1931		
1904	427	1904	86	1905	30	1909
	12	1915	9	1925		
1905	392	1907	7	1908	90	1910
	732	1911	34	1913	48	1914
	921	1923	119	1925	65	1926
	31	1929				
1906	81	1908	56	1910	67	1916
	100	1926	425	1930		
1907	58	1908	12	1909	428	1910
	30	1911	78	1915	109	1918
	120	1921	44	1925	420	1929
	46	1930				
1908	120	1909	5	1910	615	1914
	168	1915	11	1916	87	1918
	349	1929	203	1931	7	1932
1909	15	1909	23	1911	35	1914
	337	1915	385	1925	727	1926
	17	1927	191	1931	35	1933
1910	12	1911	12	1912	26	1914
	547	1926	247	1931	22	1932
	500	1934				
1911	50	1915	22	1918	17	1919
	233	1926	17	1928	627	1931
1912	12	1912	206	1914	377	1916
	14	1917	12	1930		
1914	14	1915	206	1917	125	1932
1915	19	1916	645	1921	147	1925
	98	1926	9	1935		
1916	32	1916				
1917	65	1926				
1918	905	1919				
1919	20	1924	246	1926	1,250	1928
	76	1932	1,661	1938		
1920	14	1930	6	1931		
1921	40	1921	60	1926	267	1935
1923	68	1924				
1924	15	1926	20	1927	40	1931
1925	71	1926	10	1927	25	1929
	82	1930	32	1931		
1926	18	1927	12	1929		
1927	15	1927	395	1928	102	1929
1928	54	1929	200	1930	547	1931
	22	1932				
1929	38	1931	1,020	1934	517	1938
	14	1940				
1930	4	1933	6	1935		

8-in. Cast-Iron Unlined Mains

Year	Feet			Year	Feet		
Installed	Installed	In Service	Retired	Installed	Installed	In Service	Retired
1822	1,680	1,680	0	1898	19,694	19,546	148
1823	1,421	1,395	26	1899	16,695	16,579	116
1824	4,321	4,257	64	1900	6,585	6,585	0
1826	1,703	1,703	0	1901	3,726	3,705	21
1827	2,223	2,223	0	1902	3,620	3,270	350
1829	2,181	1,890	291	1903	45,719	45,462	257
1835	1,570	1,528	42	1904	4,048	4,039	9
1841	500	500	0	1905	12,637	12,637	0
1845	500	500	0	1906	13,917	13,773	144
1853	12	0	12	1907	7,145	6,632	513
1855	876	876	0	1908	15,671	15,608	63
1856	685	630	55	1909	9,631	9,556	75
1857	3,535	3,535	0	1910	20,206	20,206	0
1858	3,713	3,713	0	1911	47,844	47,785	59
1859	2,737	2,737	0	1912	34,351	34,250	101
1860	2,693	2,659	34	1913	39,943	39,869	74
1861	762	762	0	1914	69,281	69,274	7
1863	842	842	0	1915	90,054	89,229	825
1864	1,369	1,369	0	1916	60,180	60,093	87
1865	2,026	2,026	0	1917	50,874	49,525	1,349
1866	412	412	0	1918	21,178	21,167	11
1869	3,680	2,830	850	1919	18,717	18,717	0
1870	2,665	2,665	0	1920	28,820	28,820	0
1871	1,732	1,732	0	1921	35,706	35,554	152
1873	3,534	1,366	2,168	1922	75,515	74,445	1,070
1874	10,755	10,755	0	1923	68,812	68,756	56
1875	5,072	5,072	0	1924	77,897	77,857	40
1876	5,475	5,415	60	1925	187,655	187,451	204
1878	891	891	0	1926	137,047	136,668	379
1881	3,912	3,912	0	1927	123,021	123,021	0
1882	1,134	1,123	11	1928	81,375	81,345	30
1883	5,282	5,282	0	1929	66,327	66,322	5
1884	831	831	0	1930	76,598	76,592	6
1886	2,766	2,766	0	1931	49,469	49,469	0
1887	3,913	3,913	0	1932	15,071	15,071	0
1888	3,608	3,608	0	1933	2,909	2,909	0
1889	326	326	0	1934	7,595	7,595	0
1890	1,959	1,934	25	1935	6,348	6,348	0
1891	3,284	3,284	0	1936	10,363	10,363	0
1892	10,856	10,202	654	1937	12,956	12,956	0
1893	22,021	21,124	897	1938	16,208	16,208	0
1894	32,277	31,372	905	1939	27,263	27,263	0
1895	8,314	8,314	0	1940	14,688	14,688	0
1896	16,934	16,621	313				
1897	11,336	10,847	489	Total	1,931,677	1,918,630	13,047

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1823	26	1907					1856	55	1930				
1824	64	1907					1860	34	1926				
1829	210	1881	81	1925			1869	850	1893				
1835	42	1900					1873	49	1893	52	1921	1,280	1927
1853	12	1913						787	1931				

8-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years (contd.)

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*	*Year Installed*	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1876	60	1925					1909	75	1910				
1882	11	1931					1911	12	1916	47	1926		
1890	25	1908					1912	97	1926	4	1931		
1892	77	1901	56	1932	521	1935	1913	34	1913	10	1920	30	1922
1893	751	1925	146	1927			1914	7	1914				
1894	93	1896	156	1905	376	1908	1915	130	1922	30	1923	379	1926
	28	1911	5	1915	28	1921		286	1927				
	219	1930					1916	10	1920	77	1938		
1896	20	1897	164	1931	129	1935	1917	17	1925	798	1926	534	1931
1897	489	1932					1918	11	1920				
1898	26	1901	122	1931			1921	120	1926	32	1930		
1899	116	1932					1922	817	1926	253	1927		
1901	21	1920					1923	56	1930				
1902	350	1910					1924	40	1927				
1903	61	1904	19	1906	83	1910	1925	204	1931				
	84	1916	10	1918			1926	300	1928	79	1931		
1904	9	1910					1928	15	1930	15	1931		
1906	144	1917					1929	5	1931				
1907	513	1928					1930	6	1931				
1908	63	1914											

10-in. Cast-Iron Unlined Mains

Year Installed	*Feet Installed*	*Feet In Service*	*Feet Retired*	*Year Installed*	*Feet Installed*	*Feet In Service*	*Feet Retired*
1821	132	0	132	1857	600	600	0
1823	2,352	2,218	134	1859	2,516	2,413	103
1824	2,552	2,400	152	1860	5,238	5,238	0
1825	2,025	2,025	0	1861	142	142	0
1826	7,935	7,305	630	1862	890	890	0
1827	16,479	15,380	1,099	1863	1,838	1,838	0
1828	16,243	14,075	2,168	1864	840	840	0
1829	825	825	0	1865	1,182	748	434
1830	7,556	7,514	42	1866	3,274	1,992	1,282
1831	4,086	3,886	200	1867	1,164	1,164	0
1832	3,567	3,177	390	1868	7,987	6,568	1,419
1833	3,669	3,669	0	1870	2,494	2,494	0
1834	2,672	2,662	10	1871	84	84	0
1835	15,461	14,819	642	1872	10,315	10,315	0
1836	1,207	1,152	55	1874	6,720	6,100	620
1837	1,397	1,397	0	1875	21,086	20,561	525
1839	2,257	2,257	0	1876	6,136	6,136	0
1840	4,882	4,230	652	1877	3,519	3,411	108
1841	391	391	0	1878	1,188	1,064	124
1843	1,246	1,246	0	1879	4,575	4,149	426
1844	7,457	7,457	0	1880	1,760	1,760	0
1845	17,342	17,342	0	1881	1,029	1,029	0
1846	2,760	2,760	0	1882	4,491	4,491	0
1851	37	0	37	1883	10,829	10,771	58
1852	8,442	8,432	10	1884	346	323	23
1853	1,105	1,105	0	1885	2,303	1,741	562
1855	2,169	2,169	0	1886	11,531	11,486	45

10-in. Cast-Iron Unlined Mains (contd.)

Year Installed	Feet Installed	Feet In Service	Feet Retired
1887	1,369	1,369	0
1888	1,780	1,780	0
1889	822	822	0
1890	3,442	3,403	39
1891	3,530	3,496	34
1892	9,843	9,843	0
1893	6,377	6,093	284
1894	11,459	11,357	102
1895	5,450	5,450	0
1896	19,864	19,775	89
1897	6,931	6,608	323
1898	12,609	12,567	42
1899	13,023	13,023	0
1900	34,085	33,038	1,047
1901	10,468	10,373	95
1902	5,841	5,841	0
1903	19,179	19,129	50
1904	18,530	18,389	141
1905	16,444	16,424	20
1906	19,614	19,597	17
1907	8,093	8,093	0
1908	17,926	17,919	7
1909	13,874	13,829	45
1910	6,542	6,313	229
1911	5,926	5,913	13
1912	9,616	9,616	0
1913	15,433	15,382	51
1914	20,728	20,728	0
1915	20,742	20,694	48
1916	14,005	14,005	0
1917	5,082	5,082	0
1918	3,975	3,975	0
1919	2,096	2,096	0
1920	11,005	10,228	777
1921	12,296	12,281	15
1922	1,411	1,411	0
1923	623	623	0
1924	18	18	0
1925	202	202	0
1926	1,547	1,547	0
1927	124	124	0
1928	690	0	690
1929	45	45	0
1931	56	28	28
1940	0	0	0
Total	643,038	626,770	16,268

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1821	70	1928	62	1931		
1823	49	1928	85	1931		
1824	19	1907	50	1908	83	1931
1826	630	1930				
1827	84	1871	45	1881	30	1898
	32	1899	108	1925	800	1931
1828	50	1927	2,105	1931	13	1932
1830	42	1908				
1831	45	1916	97	1931	58	1932
1832	390	1911				
1834	10	1911				
1835	246	1872	18	1893	36	1906
	167	1925	175	1929		
1836	55	1898				
1840	256	1863	215	1865	181	1925
1851	37	1911				
1852	10	1890				
1859	103	1908				
1865	434	1868				
1866	642	1874	640	1895		
1868	1,419	1931				
1874	161	1903	459	1910		
1875	525	1895				
1877	108	1878				
1878	124	1926				
1879	149	1908	277	1934		
1883	58	1929				
1884	23	1908				
1885	562	1896				
1886	20	1925	25	1929		
1890	39	1925				
1891	34	1932				
1893	284	1921				
1894	8	1908	94	1934		
1896	6	1903	50	1907	33	1918
1897	26	1910	297	1925		
1898	42	1932				
1900	18	1901	186	1906	60	1908
	700	1926	83	1929		
1901	52	1911	14	1912	25	1913
	4	1925				
1903	50	1915				
1904	39	1921	102	1939		
1905	20	1921				
1906	17	1927				
1908	7	1926				
1909	45	1929				
1910	229	1925				
1911	13	1930				
1913	51	1918				
1915	48	1925				
1920	777	1930				
1921	15	1929				
1928	690	1931				
1931	28	1931				

12-in. Cast-Iron Unlined Mains

Year Installed	Feet: Installed	In Service	Retired
1825	5,885	5,763	122
1827	508	508	0
1828	800	800	0
1831	1,340	1,340	0
1832	1,456	1,440	16
1835	3,348	3,348	0
1836	849	849	0
1837	213	213	0
1840	308	308	0
1842	1,113	1,080	33
1843	4,095	4,095	0
1844	400	400	0
1846	490	490	0
1847	2,669	2,669	0
1848	446	446	0
1849	469	420	49
1850	1,976	1,795	181
1853	414	382	32
1857	2,558	2,558	0
1859	12,792	12,323	469
1861	1,392	1,392	0
1862	1,058	1,019	39
1865	1,448	1,448	0
1866	2,882	2,882	0
1868	2,515	2,515	0
1869	4,836	4,073	763
1870	680	680	0
1871	4,045	4,045	0
1872	336	336	0
1873	10,503	10,258	245
1874	6,803	6,803	0
1875	6,279	6,214	65
1876	12,109	12,049	60
1877	3,611	3,611	0
1878	3,020	3,020	0
1879	6,896	3,047	3,848
1881	16,483	13,419	3,064
1882	1,511	1,511	0
1883	10,966	10,545	421
1884	13,059	13,059	0
1885	26,426	24,598	1,828
1886	12,928	12,393	535
1887	3,381	3,381	0
1888	3,350	3,018	332
1889	13,358	4,759	8,599
1890	10,908	10,908	0
1891	9,718	8,139	1,579
1892	8,148	5,126	3,022
1893	20,920	20,775	145
1894	35,293	34,148	1,145
1895	20,130	16,607	3,523
1896	36,149	35,833	316
1897	18,767	18,549	218
1898	25,457	24,450	1,007
1899	34,566	34,183	383
1900	18,877	15,295	3,582
1901	17,978	17,893	85
1902	3,105	2,971	134
1903	10,300	10,160	140
1904	13,761	13,761	0
1905	9,173	7,290	1,883
1906	12,217	10,183	2,034
1907	11,703	9,304	2,399
1908	11,534	11,000	534
1909	5,627	5,539	88
1910	13,832	13,747	85
1911	16,616	15,648	968
1912	28,537	28,470	67
1913	11,925	11,810	115
1914	26,445	26,356	89
1915	21,408	20,486	922
1916	10,528	10,528	0
1917	12,464	12,464	0
1918	4,578	4,578	0
1919	9,214	9,214	0
1920	3,824	3,764	60
1921	20,399	20,319	80
1922	36,190	35,901	289
1923	15,058	15,058	0
1924	54,641	54,537	104
1925	80,325	80,313	12
1926	81,307	80,711	596
1927	18,683	18,683	0
1928	13,137	13,137	0
1929	30,368	30,368	0
1930	31,102	31,102	0
1931	22,588	22,588	0
1932	6,544	6,544	0
1934	1,053	1,053	0
1935	13,761	13,761	0
1936	191	191	0
1937	6,717	6,717	0
1938	11,994	11,994	0
1939	5,303	5,303	0
1940	1,591	1,591	0
Total	1,156,658	1,110,352	46,306

12-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1825	17	1925	105	1931		
1832	16	1929				
1842	33	1929				
1849	49	1929				
1850	181	1931				
1853	32	1930				
1859	459	1902	10	1903		
1862	39	1931				
1869	175	1877	588	1930		
1873	245	1906				
1875	65	1877				
1876	12	1885	48	1908		
1879	175	1917	3,674	1919		
1881	242	1886	896	1924	1,926	1925
1883	421	1922				
1885	497	1895	485	1904	628	1910
	12	1911	120	1923	86	1931
1886	242	1896	293	1916		
1888	332	1904				
1889	896	1901	1,088	1904	901	1905
	1,365	1906	297	1907	32	1909
	3,443	1925	577	1926		
1891	439	1904	586	1925	540	1926
	14	1931				
1892	1,389	1904	539	1906	1,060	1924
	34	1925				
1893	48	1925	5	1926	4	1930
	88	1931				
1894	262	1896	468	1899	219	1925
	196	1935				
1895	1,260	1898	497	1900	907	1901
1895	16	1904	23	1905	537	1913
	217	1916	66	1930		
1896	158	1898	75	1907	54	1910
	29	1930				
1897	86	1903	42	1908	77	1914
	13	1926				
1898	48	1905	72	1926	860	1929
	27	1932				
1899	383	1922				
1900	17	1903	1,600	1917	1,965	1930
1901	85	1926				
1902	134	1927				
1903	112	1929	28	1931		
1905	43	1908	1,840	1916		
1906	2,034	1932				
1907	2,399	1932				
1908	534	1931				
1909	36	1917	52	1919		
1910	85	1926				
1911	107	1915	860	1916	1	1931
1912	67	1918				
1913	30	1914	85	1916		
1914	9	1914	80	1929		
1915	922	1927				
1920	60	1927				
1921	80	1927				
1922	70	1923	219	1931		
1924	104	1929				
1925	12	1925				
1926	305	1926	291	1930		

16-in. Cast-Iron Unlined Mains

Year	Feet		
Installed	Installed	In Service	Retired
1829	1,046	936	110
1830	447	400	47
1831	1,308	1,308	0
1832	1,338	1,338	0
1834	2,131	2,131	0
1836	1,471	1,420	51
1844	1,338	1,338	0
1845	17,311	14,489	2,822
1848	1,725	1,674	51
1850	1,288	1,288	0
1858	4,681	4,681	0
1859	2,235	2,235	0
1867	1,170	1,170	0
1868	1,284	1,284	0
1871	8,908	8,826	82
1872	1,573	1,573	0
1873	5,872	5,872	0
1874	12	12	0
1875	828	828	0
1877	175	175	0
1879	12	12	0
1881	179	179	0
1882	536	536	0
1884	16,126	15,926	200
1885	2,966	2,966	0
1886	1,065	1,065	0

16-in. Cast-Iron Unlined Mains (contd.)

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1887	1,297	1,297	0
1888	6,329	6,275	54
1889	376	376	0
1890	446	446	0
1891	4,084	4,084	0
1892	144	144	0
1893	561	543	18
1894	8,881	8,877	4
1895	61	56	5
1896	8,405	8,314	91
1897	8,938	8,938	0
1898	2,042	2,042	0
1899	2,872	2,872	0
1900	9,393	9,393	0
1901	1,929	1,929	0
1902	27	27	0
1903	12,396	12,396	0
1904	2,687	2,687	0
1905	5,974	5,959	15
1906	13,302	13,180	122
1907	11,333	11,333	0
1908	7,616	7,616	0
1909	4,123	4,123	0
1910	7,255	7,255	0
1911	1,110	1,110	0
1913	963	963	0
1914	1,818	1,818	0
1915	10,951	10,951	0
1916	10	10	0
1919	5,104	5,104	0
1920	882	882	0
1921	6,748	6,748	0
1922	13,697	13,293	404
1923	901	901	0
1924	6,209	6,209	0
1925	9,469	9,469	0
1926	24,641	24,641	0
1927	3,967	3,967	0
1928	147	147	0
1929	358	358	0
1930	1,338	1,338	0
1931	550	550	0
1932	3,107	3,107	0
1933	1,194	1,194	0
1934	143	143	0
1940	0	0	0
Total	290,803	286,727	4,076

Retirements by Years

Year Installed	*Feet*	*Year*	*Feet*	*Year*	*Feet*	*Year*
1829	110	1928				
1830	47	1925				
1836	51	1928				
1845	1,170	1867	1,286	1887	267	1892
	99	1926				
1848	51	1928				
1871	82	1894				
1884	200	1925				
1888	54	1932				
1893	18	1932				
1894	4	1917				
1895	5	1895				
1896	20	1916	71	1932		
1905	15	1908				
1906	122	1929				
1922	404	1926				

18-in. Cast-Iron Unlined Mains

Year	Feet		
Installed	*Installed*	*In Service*	*Retired*
1890	2,021	2,021	0
1905	10	10	0
1940	0	0	0
Total	2,031	2,031	0

20-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1819	11,813	3,471	8,342
1822	322	322	0
1829	15,282	8,311	6,971
1838	5,353	0	5,353
1848	1,444	1,362	82
1859	1,936	1,920	16
1865	3,655	3,655	0
1867	15,915	11,477	4,438
1868	9,326	9,304	22
1869	12,012	11,564	448
1870	6,540	5,330	1,210
1871	1,452	1,452	0
1872	5,151	4,787	364
1873	6,604	1,570	5,034
1874	3,232	3,232	0
1875	408	408	0
1876	8,420	5,733	2,687
1877	4,080	4,080	0
1878	3,889	3,889	0
1879	7,625	5,994	1,631
1881	525	525	0
1882	10,854	5,694	5,160
1884	82	82	0
1885	14,153	13,813	340
1886	913	610	303
1887	4,034	4,034	0
1889	89	0	89
1891	18,668	18,668	0
1892	771	771	0
1893	26,132	26,076	56
1894	2,984	2,984	0
1895	370	370	0
1896	6,137	6,137	0
1897	328	328	0
1898	917	917	0
1899	1,756	1,609	147
1900	17,906	17,556	350
1901	6,938	6,938	0
1903	28,994	28,490	504
1904	7,892	7,614	278
1905	1,908	1,908	0
1906	158	158	0
1907	36	36	0
1908	1,283	1,283	0
1915	16,631	16,631	0
1918	23	23	0
1919	426	426	0
1920	2,220	2,220	0
1921	18	18	0
1922	7,264	7,264	0
1925	1,288	1,288	0
1926	76	76	0
1927	35	35	0
1928	2,076	2,043	33
1929	8,120	8,120	0
1930	1,056	1,056	0
1931	3,639	3,639	0
1932	4,385	4,385	0
1934	380	380	0
1935	148	148	0
1939	339	339	0
1940	0	0	0
Total	326,411	282,553	43,858

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1819	1,149	1872	7,193	1928		
1829	78	1906	6,893	1918		
1838	3,387	1928	1,966	1929		
1848	82	1932				
1859	16	1932				
1867	614	1886	1,683	1901	2,141	1927
1868	22	1896				
1869	448	1908				
1870	40	1896	1,170	1899		
1872	194	1908	170	1934		
1873	5,034	1932				
1876	2,687	1921				
1879	399	1898	700	1913	532	1930
1882	160	1908	5,000	1927		
1885	205	1908	50	1926	35	1927
	50	1935				
1886	303	1918				
1889	89	1901				
1893	38	1908	18	1932		
1899	147	1899				
1900	250	1905	100	1931		
1903	504	1927				
1904	278	1935				
1928	33	1929				

22-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1819	2,660	0	2,660
1940	0	0	0
Total	2,660	0	2,660

Retirements by Years

Year Installed	Feet	Year	Feet	Year
1819	1,578	1897	1,082	1898

24-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1871	564	564	0
1885	2	2	0
1897	1,588	1,578	10
1898	523	523	0
1904	9,245	9,245	0
1914	194	194	0
1915	1,478	1,478	0
1919	17	17	0
1920	308	308	0
1922	11,622	11,622	0
1924	10,895	10,895	0
1925	22,378	22,315	63
1926	26,192	26,192	0
1927	15,170	15,170	0
1928	433	433	0
1930	17,598	17,598	0
1931	674	674	0
1934	544	544	0
1935	98	98	0
1940	0	0	0
Total	119,523	119,450	73

Retirements by Years

Year Installed	Feet	Year
1897	10	1898
1925	63	1931

30-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1819	44	0	44
1850	14,024	11,420	2,604
1851	1,763	1,763	0
1852	7,960	6,409	1,551
1859	17,806	7,814	9,992
1865	834	834	0
1866	19,109	10,636	8,473
1867	856	376	480
1868	4,760	4,760	0
1870	3,800	3,800	0
1871	7,932	7,716	216
1872	3,111	1,698	1,413
1874	132	132	0
1876	11,316	9,620	1,696
1877	7,317	7,226	91
1878	4,187	4,187	0
1879	6,874	6,800	74
1881	747	725	22
1882	2,137	2,137	0
1884	3,226	3,226	0
1885	614	614	0
1886	5,145	3,905	1,240
1887	24,756	11,365	13,391
1888	84	84	0
1889	4,733	4,733	0
1891	10,790	9,831	959
1892	6,821	6,665	156
1893	26,611	26,540	71
1894	475	475	0
1895	32	32	0
1896	26	26	0
1898	129	109	20
1899	2,062	2,062	0
1900	33,217	33,072	145
1901	12,403	12,328	75
1902	148	148	0
1903	36,393	36,306	87
1904	1,645	1,645	0
1905	115	115	0
1906	77	77	0
1907	803	803	0
1908	1,986	1,968	18
1909	2,417	2,417	0
1910	22	22	0
1911	60	60	0
1912	813	813	0
1915	3,245	3,174	71
1916	544	544	0

30-in. Cast-Iron Unlined Mains (contd.)

Year Installed	Feet Installed	Feet In Service	Feet Retired
1918	609	609	0
1919	42	42	0
1920	162	162	0
1924	408	408	0
1925	121	121	0
1926	426	426	0
1927	6,304	6,304	0
1928	11	11	0
1929	127	127	0
1930	7,410	7,410	0
1931	109	109	0
1940	0	0	0
Total	309,830	266,941	42,889

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year
1819	44	1930				
1850	1,482	1886	799	1918	190	1919
	133	1927				
1852	78	1898	1,473	1913		
1859	7,772	1927	2,220	1932		
1866	278	1892	20	1907	8,175	1927
1867	480	1928				
1871	72	1884	144	1885		
1872	341	1892	312	1900	530	1907
	230	1908				
1876	66	1901	1,630	1923		
1877	91	1925				
1879	60	1911	14	1925		
1881	22	1903				
1886	813	1912	427	1916		
1887	232	1909	12,861	1923	298	1931
1891	959	1909				
1892	156	1926				
1893	71	1926				
1898	20	1918				
1900	145	1902				
1901	75	1901				
1903	87	1916				
1908	18	1908				
1915	71	1932				

36-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired
1830	116	116	0
1869	2,136	0	2,136
1870	10,102	8,481	1,621
1871	11,349	11,349	0
1872	3,752	3,752	0
1878	32	32	0
1881	48	48	0
1882	158	158	0
1884	3,956	3,956	0
1885	11,435	11,435	0
1886	6,994	6,493	501
1887	228	21	207
1888	199	141	58
1889	4,208	4,186	22
1890	323	323	0
1891	9,581	9,520	61
1892	1,942	1,897	45
1893	5,392	5,392	0
1894	479	479	0
1895	293	293	0
1896	528	528	0
1897	24	24	0
1898	64	46	18
1899	2,438	2,438	0
1900	6,734	6,734	0
1901	1,976	1,976	0
1904	120	96	24
1906	2,250	2,250	0
1908	23	23	0
1913	143	143	0
1916	61	61	0
1918	685	685	0
1922	10,096	10,096	0
1926	16,306	16,306	0
1927	160	160	0
1928	322	322	0
1940	0	0	0
Total	114,653	109,960	4,693

36-in. Cast-Iron Unlined Mains (contd.)

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1869	2,136	1928					1889	22	1902				
1870	206	1884	963	1886	452	1890	1891	61	1916				
1886	501	1918					1892	45	1892				
1887	207	1893					1898	18	1918				
1888	58	1895					1904	24	1907				

48-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	Feet In Service	Feet Retired	Year Installed	Feet Installed	Feet In Service	Feet Retired
1861	21	0	21	1903	11,046	10,906	140
1865	1,104	0	1,104	1904	5,782	5,782	0
1866	3,871	3,326	545	1906	15,809	12,141	3,668
1876	4,145	4,145	0	1907	620	620	0
1882	2,606	2,606	0	1909	1,197	1,197	0
1883	970	970	0	1912	14,180	14,180	0
1884	856	856	0	1914	2,018	2,018	0
1885	204	204	0	1915	31,952	31,952	0
1886	16,399	13,391	3,008	1916	4,632	4,632	0
1887	4,112	3,980	132	1917	6,137	6,137	0
1888	2,103	2,103	0	1919	42	0	42
1889	2,008	2,008	0	1920	393	393	0
1890	15,027	13,563	1,464	1921	8,597	8,597	0
1891	6,848	6,453	395	1925	1,011	1,011	0
1892	521	521	0	1926	8,308	8,308	0
1893	23,636	18,407	5,229	1927	3,309	3,256	53
1894	39,530	39,530	0	1930	194	194	0
1895	14,294	13,032	1,262	1931	53	53	0
1896	5,931	5,931	0	1932	754	754	0
1897	209	209	0	1934	170	170	0
1898	1,645	1,603	42	1940	0	0	0
1899	9,037	9,037	0				
1900	10,816	10,816	0	Total	291,740	272,666	19,074
1901	9,643	7,674	1,969				

Retirements by Years

Year Installed	Feet	Year	Feet	Year	Feet	Year	Year Installed	Feet	Year	Feet	Year	Feet	Year
1861	21	1899					1893	80	1898	265	1920	4,884	1921
1865	1,104	1921					1895	1,262	1900				
1866	545	1927					1898	42	1918				
1886	415	1898	163	1899	1,892	1927	1901	850	1921	1,119	1932		
	538	1930					1903	140	1927				
1887	132	1927					1906	1,985	1926	1,513	1932	170	1934
1890	1,464	1921					1919	42	1919				
1891	395	1927					1927	53	1931				

60-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	In Service	Retired
1921	4,230	4,230	0
1930	600	600	0
1940	0	0	0
Total	4,830	4,830	0

72-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	In Service	Retired
1930	13,514	13,514	0
1940	0	0	0
Total	13,514	13,514	0

93-in. Cast-Iron Unlined Mains

Year Installed	Feet Installed	In Service	Retired
1930	13,150	13,150	0
1940	0	0	0
Total	13,150	13,150	0

12-in. Steel Mains

Year Installed	Feet Installed	In Service	Retired
1930	1,214	1,214	0
1931	1,347	1,347	0
1932	240	240	0
1940	0	0	0
Total	2,801	2,801	0

16-in. Steel Mains

Year Installed	Feet Installed	In Service	Retired
1935	120	120	0
1940	0	0	0
Total	120	120	0

20-in. Steel Mains

Year Installed	Feet Installed	In Service	Retired
1908	151	151	0
1940	0	0	0
Total	151	151	0

30-in. Steel Mains

Year Installed	Feet Installed	In Service	Retired
1930	1,138	1,138	0
1931	75	75	0
1932	377	377	0
1940	0	0	0
Total	1,590	1,590	0

36-in. Steel Mains

Year Installed	Feet Installed	In Service	Retired
1921	850	850	0
1927	164	164	0
1940	0	0	0
Total	1,014	1,014	0

48-in. Steel Mains

Year Installed	Feet Installed	In Service	Retired
1901	48	48	0
1906	10,828	10,828	0
1907	3,294	3,294	0
1924	9,329	9,329	0
1926	288	288	0
1927	6,303	6,303	0
1932	1,729	1,729	0
1940	0	0	0
Total	31,819	31,819	0

60-in. Steel Mains

Year Installed	Feet Installed	In Service	Retired
1921	2,739	2,739	0
1940	0	0	0
Total	2,739	2,739	0

93-in. Steel Mains

Year Installed	Feet Installed	In Service	Retired
1930	5,651	5,651	0
1940	0	0	0
Total	5,651	5,651	0

Abstracts of Water Works Literature

Key: In the reference to the publication in which the abstracted article appears, **34:** 412 (Mar. '42) indicates volume 34, page 412, issue dated March 1942. If the publication is paged by the issue, **34:** 3: 56 (Mar. '42) indicates volume 34, number 3, page 56, issue dated March 1942. Initials following an abstract indicate reproduction, by permission, from periodicals, as follows: *B.H.—Bulletin of Hygiene* (*British*); *C.A.—Chemical Abstracts; P.H.E.A.—Public Health Engineering Abstracts; W.P.R.—Water Pollution Research* (*British*); *I.M.—Institute of Metals* (*British*).

DISTRIBUTION SYSTEMS—CONSTRUCTION AND MAINTENANCE

Progress of Civilization Can Be Traced in History of Piping. ANON. 'Bama Beam, Univ. of Alabama (Mar. '44). Although pipes have been used for 5000 yr. for carrying water, it was less than 100 yr. ago that first globe valve introduced in this country. First pipes on record were twin tubes of clay, found at Nippur, the home town of Abraham in Babylon. The father-in-law of King Tut had brass or copper drain pipes run to pyramids. Egyptian priests said to have connected a steam boiler, placed over altar, to hidden cylinder, piston of which opened and closed temple doors without human aid. King Minos of Crete, in 2000 B.C., used terra cotta water and drain pipes, and apartment of his queen had bathing pool. 1000 yr. later saw tunnels dug through solid rock to bring water to temple in Jerusalem. Some of these tunnels still in use. Greece, Rome and Carthage all used pipes of either hollow logs, terra cotta, bored stone or lead. Some of these pipelines laid under streets. Underground aqueduct in Syracuse still in service. By 97 A.D. Rome had 9 aqueducts, of which 4 used today. Leaks stopped by throwing ashes in water. 247 reservoirs supplied 39 ornamental fountains and 591 public water basins, day and night. Lead pipes made by bending sheets of metal around wooden forms, and pouring molten lead in joints. Old pipes, up to 27" in diam. and with $1\frac{1}{4}$" walls, still to be seen. Pressure tests made on such lead piping—4" id., with $\frac{1}{4}$" walls—show it capable of withstanding pressures of over 100 lb. safely, failure being noted at 250 lb. Plumber marked name of his customer and his own name on each length of pipe, partly to prevent unscrupulous tapping of lines. In ancient Pompeii, bathing pools in certain private homes heated by bldg. fires beneath their concrete floors. Hollow tiles in walls warmed rooms as well as water. Baths built by Emperor Diocletian accommodated 3200 persons. (Pennsylvania R.R. Station in New York City designed after and occupies about same space as the bldg. which housed baths of Caracalla at Rome.) Some 1500 yr. passed before, at end of Dark Ages, interest in piping revived. Wooden aqueducts and hundreds of miles of wooden mains laid in London about 1610. Cast-iron pipe first used for fountains of Versailles, in 1664. When rusting of bolts used on flanges made trouble, Thomas Simpson developed bell and spigot joint (London, 1785). 25 yr. previous, continuous lengths of lead pipe produced in France. Beginning in 1792, gas pipelines followed those installed for water and drainage. Boston, Bethlehem, New York, Philadelphia and Baltimore among first towns to have water and gas lines in America. Cast-iron pipe imported from England, after bored pine logs tried. Wood stave constr. persisted until 1860's. Water wagons were on streets of New York just before Civil War, with signs reading "Tea Water 1c a pail." Benjamin Franklin defied public opinion by bathing in giant copper tub. Early Virginians taxed $30 a year on bath tubs, and Boston made bathing unlawful except on medical advice. Steam heat, as we think of it, unknown two generations ago. 125 lb. was std. steam pressure used through 19th Century. 250 lb. considered high pressure up until about '14. This had risen to 600 lb. by '23, and 2 yr. later first plant using 1200 lb. pressure put in service.—*Ed.*

Notes on the Prevention of Frost Failures in Water Distribution Systems. W. BODEN. Wtr. & Wtr. Eng. (Br.) **48**: 569 (Oct. '45). During severe winter of '39–'40 breakages almost entirely confined to small pipes and invariably circumferential, with tendency to occur at service connections, particularly when service pipes were of steel or wrought iron. Cast iron not weakened by cooling to temps. as low as liquid air. Contraction due to cooling is insufficient to develop longitudinal stress required to break pipe and joints will "draw" at axial loads considerably less than those needed to cause fracture. Service hole reduces resistance of pipe to transverse bending by 50%, provided hole is located in zone of max. tension. Above facts indicate frost failures arise from transverse stress in pipe. As ground is frozen it expands. Progressive freezing imparts load on pipeline as upward expansion usually restricted by solidity of road or footpath. Fractures as numerous on gas as on water pipes. Frost fractures can be minimized by using pipes of proven qual. laid on well-prepd. beds. New gas main laying technic, which involves use of flexible jointed pipes surrounded by bottomless wooden box, may, through insulating main from top loading, provide immunity from frost failure. Problem of frost protection for service pipes has been investigated by Power, who found that expansion due to freezing could be accommodated by threading through pipe tight-fitting strip of expanded rubber, having sufficient compressibility to accommodate effect of mains' pressure plus 9% water-ice expansion. Another method involves fitting, at selected points, of pressure relief valves in exposed pipelines. General conclusion is that problem of frost damage can be reduced to one of negligible importance.—*H. E. Babbitt.*

Control of Fractures in Water Distribution Systems. W. E. MACDONALD. Wtr. & Sew. **83**: 3: 17 (Mar. '45). To facilitate rapid isolation, shut-control book has been prepd. in Ottawa which is supplementary to books of intersection plans in use many years. Each feeder main divided into shortest possible sections, each wholly contained by valves, page of book being devoted to each such section, with list of all valves that must be closed. Isometric drawings included where plan not sufficiently explanatory. Emergency truck maintd. equipped with tools, supplies, plans, copy of shut-control book and valve-turning mechanism driven by auxiliary drive shaft connected to transmission. Specimen pages from book included.—*R. E. Thompson.*

Location of Buried Pipes and Detection of Leaks in Mains. ANON. Wtr. & Wtr. Eng. (Br.) **48**: 517 (Sept. '45). Latest methods of locating buried pipes and detecting leaks in mains employ elec. instruments which give audible indication of route of underground pipe or presence of leak. Principle of "Sharman" Main and Service Finder is sending of elec. current from generator along pipe; search coil traces course of current and, therefore, course of pipe, which is marked on ground. In operation generator and "earth" must be well away from assumed place of lost pipe. Otherwise operator may be misled by sounds picked up from generator. Depth indicator shows depth of buried pipe. Finder can also be used for tracing non-metallic pipes by means of insulated flexible wire, first pushed through pipe by means of rods. Elec. stethoscope specially designed for locating leaks in water mains where ordinary stethoscope would be useless. By means of amplifier it can be rendered more sensitive and used in conjunction with main finder. Set comprises microphone with double telephones and head band, battery and switch, all housed in carrying case. All parts permanently coupled and need only to remove microphone and telephone from case and close switch when set is ready for use.—*H. E. Babbitt.*

Compressed Air Flushing of Small Mains. R. F. BROWN. W.W. & Sew. **91**: 110 (June '44). Calif. Water Service Co. of Stockton, Calif., has great many 2" lines in thinly populated areas of town. In effort to alleviate taste and odor problems small mains and dead ends flushed approx. every 2 mo. by opening fire hydrants and flusher valves. Method did little more than freshen water in mains. All dead ends and all blocks of 2" lines have had flusher risers installed. Compressed air of 90-lb. pressure from portable compressor introduced into mains through service connection midway between two flusher risers, after intervening services have been cut off. After water expelled from risers, air cut off and water under normal pressure of 45 lb. allowed to enter mains. Procedure followed until all evidence of scale and foreign matter elimd. from wash water. Not only elimd. taste and odor complaints but increased carrying capac. of 2" lines. Cost between 60¢ and 90¢ per 100'.—*P.H.E.A.*

Scraping of Large Mains. J. F. Bailey. Surveyor (Br.) **103**: 295 (June 23, '44). Author's authority has carried out scraping of mains since '37 with result that effective discharge of aqueduct maintd. [For description of scraping machine see Jour. A.W.W.A. **36**: 490 (Apr. '44).] Three different methods employed by which scraping assembly inserted into c-i. portion of aqueduct: (1) through c-i. hatch box built in pipe; (2) in valve chamber at point where cut-and-cover section finishes and pipeline commences; and (3) through dowel held in position by Johnson couplings. Scraping of typical main done week-ends when consumption not so high. First 3 lengths of pipe hand-scraped. Assembly for this run consists of 2 scrapers followed by 1 pair of brushes blanked off to act as pistons. Scraper inserted and main slowly charged up to ascertain if scraper has moved. Men then dispersed along track to take up respective listening posts, signaling points, etc. When scraper approaches within 100–200 yd. of dowel, man controlling penstock valve closes it. On arrival of scraper at scour water becomes very dirty, scour is slowly opened at full and main emptied. In brushing steel mains work identical to procedure adopted for scraping of c-i. mains. Results obtained after scraping and brushing have been gratifying. *Discussion:* S. G. Barrett: Scraping of mains to be avoided if possible. Dimunition of discharge due to nodular incrustation seems eventually to reach max. after which further falling off of discharge small. Rate of incrustation accelerated after scraping. Almost certain that protective lining of pipe will be damaged after scraping. At Torquay estd. that after 41 yr. iron lost by corrosion amounted to $\frac{1}{4}''$ off whole inner surface of pipe. In author's time-table shown that $2\frac{3}{4}$ hr. taken up in putting scraper in, $1\frac{1}{2}$ hr. to take it out, as compared with $1\frac{1}{2}$ hr. actual scraping time. Pipe better scraped at beginning of run than at end, a serious defect of machine. As regards to damage of sluice valves, serious risk of damage to valve seating rings and probability of machine being jammed in pipe. In "wet pipe" method scraper inserted in main fully charged with water and actuation of machine effected by opening downstream scour valves. Method usually applied to large mains in hilly country. "Dry pipe" method can be adopted in level country when scraper can be inserted into empty pipe and projected by water pressure to open end at some other point in pipeline. D. Lloyd: In notable paper "Deposits in Pipes," J. Campbell Brown (Proc. Inst. Civ. Eng. **156**: 1 ('04)), range deposits in water pipes into (1) incrustations, (2) deposits of slime due to iron bacteria, and (3) debris. He would not advise corp. to scrape. These remarks do not apply to small mains. Possible to remove only deposits of iron bacteria on Welsh aqueduct by brushing machine without iron scraper. Means of checking growth of iron bacteria are: (1) introducing conditions fatal to growth and (2) removing its food. Killing is practicable by initial heavy chlorination followed by continuous dosing, while removal of food appears possible by reducing hydrogen-ion concn. in water. *Author's reply:* On examn. of pipe after scraping, no deterioration in scraping found toward end of run. Second scraper damages brass rings. If possible, scraping assembly should never be run through large valves. Avg. per yd. of scraping of 36″ pipeline is 6*d*. per yd. Scraping of mains indefinitely without relining would certainly shorten life of pipe.—*H. E. Babbitt.*

A New Pipe Scraping Machine. Anon. Wtr. & Wtr. Eng. (Br.) **46**: 493 (Dec. '43). Scraping knives of machine spring loaded and mounted on light section of cylindrical steel body, stiffened where necessary. Brush unit combined integrally with scraper. Bristles spring loaded in similar manner to scraping knives, which are bolted to steel guide blades running full length of machine. Wt. of 3″ machine about 4 cwt. Among advantages claimed: cheapness, lightness, simplicity, means of adjustment of pressure of knives, reduction of risk of machine stoppage in pipe, practical elimn. of risk of damage to sluice valve rings, low operating pressure and small maint. costs. Discharge of 30″ pipeline increased by scraping operations by 25.3%. Scraping time, 18 hr. spread over 4 days (for scraping 26-mi. pipeline). 8 men employed and total scraping costs about £200.—*H. E. Babbitt.*

Topeka's Two-Million-Gallon Water Tower. Anon. Am. City **58**: 51 (July '43). Attractive reinforced architectural concrete water tower, 150′ high, 2 mil.gal. in upper chamber (tank) and 1 mil.gal. in base, built in residential neighborhood and completed in Jan. '43. Foundation extends 20′ below ground to bedrock, 100′ diameter, is 5′ thick monolithic reinforced concrete slab. Above this slab

are 4 concentric rings of reinforced concrete reaching to ground level. Outside ring is 18′ thick and 90′ in diam. This ring space below ground level is base water storage. To prevent stagnation water circulation ports provided in walls. Ground-level slab 30″ thick, holding 4 more concentric rings to support overhead storage tank. Outside ring is 167′ semicircular grooves. Overhead tank 27′ high, 90′ in diam., separated from rest of tank to minimize temp. stresses and possible cracking. Supporting floor has thick layer of tar paper. Inside walls waterproofed by asphalt membrane. Tank sealed at top by 6″ monolithic concrete slab. Center cylinder with steel ladder providing access from ground to roof. Inflow controlled and overflow prevented by 18″ Ross double-acting altitude valve located inside structure in ground floor. Tank part of 315-mi. distr. system serving 18,500 connections inside city and 3000 outside, with daily consumption of 4 mil.gal. with 10 mil.gal. as peak demand. Avg. per capital consumption 60 gpd.—*C.A.*

Construction and Operation of Water Works for Small Communities. DALHAUS. Tech. Gemeindeblatt (Ger.) **45**: 113 ('42). Deals with properties desirable in water to be used for supplying small community. Characteristics discussed include hardness; temp.; contents of Fe, Mn, and free CO_2; and numbers of bacteria. Small places usually obtain their water supplies from wells. Amt. of water which can be withdrawn from supply of ground water limited, and extensive tests necessary to det. amt. of water available. In small towns and villages without water-borne sewage systems, water demand per day amts. to about 50 l. per head for men and larger animals and 15 l. per head for smaller animals. In designing distr. system allowance must be made for max. demand on a hot dry day. Increased supply must be provided if water required for fire extinguishing. Often necessary to remove Fe from water supplies of small communities. Small communities should use water which does not contain many bacteria so that disinfection not necessary. Regulations governing use of ground water in Germany summarized. Costs of constructing and operating water supply system discussed. Cast iron generally used for constr. of water mains. Lead pipes used for house connections and in houses when water not corrosive, but for water which attacks lead, steel pipes coated with bitumen more suitable. Water should be examd. chemically at least once a year, and bacteriologically 2–4 times each year. Precautions must be taken to prevent poln. of wells with human or animal excreta. In some cases possible for small community to purchase water in bulk from neighboring large water works.—*C.A.*

Pipe Proportioning in Domestic Water Supply Systems. A. MOODY. Surveyor (Br.) **103**: 219 (May 12, '44). In case of private bldg. estates too many examples of service pipes of inadequate capac. exists. Obviously, provision of ½″ or ¾″ service pipe, irrespective of pressure in supply main, as worthy of censure as provision of 4″ sewer to meet all conditions of flow and gradient. Loss of head by friction per 100′ of pipe $= KVn \div d$ ft. in which d is in in., V in fps., $n = 1.8$ and K for new clean pipes, of lead $= 0.94$, of iron $= 1.06$, and of copper $= 0.86$. Loss of head due to bends, etc., stated in equiv. length of pipe, in terms of pipe diams., is: 90° bend, 15; elbow, 30; 45° spring, 15; tee, flow along main, 60; tee, flow entering branch, 90; gate valves, 10; globe valves, 45. Flow required for normal fixtures in gpm. (Imp.): bath, 3; lavatory, 2½; water closet cistern, 2; cold feed tank, 1½; sink, 3; shower, 3. Two cardinal rules to be observed in detg. pipe sizes in system: (1) Det. discharge point most likely to fail and rate of loss of head in supply pipe to that point. Discharge point in question always point having least value of fraction (available head loss ÷ distance from main). (2) This rate must not be exceeded in any part of pipe between discharge point and main.—*H. E. Babbitt.*

Water Supply: Light Steel Concreted Communication Pipes. JOHN FRANCIS HASELDINE. J. Inst. Civ. Engrs. (Br.) **20**: 87 (Apr. '43). Following practice adopted as wartime measure to economize in use of lead in service pipes which are mostly ½″ in diam. Under-pressure ferrule inserted in top of main and 2′ coil of ½″ lead pipe joined to it. Ferrule fixed at angle to insure that subsidence in lead pipe or in service will tend to tighten screwed joint connecting ferrule to main by causing it to rotate in clockwise direction. Lead pipe connected to light-weight steel pipe by means of std. plumber's union. Steel tube surrounded with protective coating of at least 3″ of cement of 4:2:1 mixture by vol.—*H. E. Babbitt.*

Laying a 36″ Diameter Main Through a Large City. ANON. Wtr. & Wtr. Eng. (Br.) **46**: 507 (Dec. '43). Dist. supplied until '41 with 27″ main fed by 36″ on north side of river, crossing bridge, thence westward diminished to 24″. In view of urgency of matter, decided to investigate again unused tunnel as means of crossing river. Scheme involves laying of 36″ main westwards from point of connection for about 600 yd. to northern end of tunnel, thence through tunnel to 24″ main at present supplying dists. Before main put into operation super-chlorinated to residual of 50 ppm.—*H. E. Babbitt.*

SOFTENING AND IRON REMOVAL

The Use of Sodium Hexametaphosphate (Calgon) as Applied to the Treatment of Chalk Well Waters. (Abridged) E. G. B. GLEDHILL & A. W. H. MCCANLIS. Wtr. & Wtr. Eng. (Br.) **48**: 67 (Feb. '45). This précis approx. $\frac{1}{10}$ length of complete paper. Relates chiefly to use of sodium hexametaphosphate in connection with treatment of chalk well waters but reference made and some details given of other applications of this chem. Discovered in 1833, its use for water works purposes not known until about '37. Until recent years treatment in most general use was carbonation, i.e., injection of CO_2 into water. As alternative, acids other than CO_2 may be substituted. Cost of Calgon shown to be well below that of cheapest acid. Action of Calgon essentially phys. and may be due to interchange of electrons from Calgon molecules to molecules of chalk, or vice versa, just as chalk is about to come out of soln. This has given rise to use of term "threshold treatment." Tests clearly indicated that Calgon as efficient as CO_2 for stabilizing treatment and that dosage of 0.5 ppm. sufficient. "Stability," for purpose of test, defined by "no increase in any minute deposit which may be present after sampling, together with const. pH value after standing for 1 wk. at atm. pressure." In all cases where samples have been examd. after standing for 3 days, over 95% stable when checked by modified form of Langelier test. In one test box (A) suspended in channel through which uncalgonized lime-softened water flowing, and other box (B) suspended in channel through which calgonized lime-softened water flowing. Amt. of Calgon in calgonized water avgd. 0.35–0.5 ppm. Samples removed after 6 mo. and again after 12 mo. immersion. Box suspended in calgonized water free from any deposit, while one suspended in uncalgonized channel completely covered with soft chalk. Known that 15″ c-i. main from softening tanks to carbonating chamber encrusted with $CaCO_3$ deposit. Calgon injected into water as near as possible to end of main. After few months noticed that large pieces of hard chalk scale being deposited in open channel. Scale collected and weighed nearly 2 cwt. Established that mains receiving softened water after stabilization reasonably free from deposit. Shortly after introduction of Calgon for stabilization in place of CO_2 at Sutton Water Works, marked indications that corrosion taking place in metal parts of Calgon dosing plant. Soda ash used to raise pH of Calgon soln. Calgon soln. is 2% by wt., and 0.2% of soda ash by wt. added. Corrosion continued. In view of this, further tests made and pH of Calgon soln. increased to over 8.4 by addn. of 0.6% by wt. of soda ash. Experience has shown that if pH not less than 8.4, no material corrosion. In case of lead and copper "calgonized" artificial waters picked up more metal from pipes than corresponding uncalgonized samples. In tests using natural waters both lead and copper less solvent in calgonized than in uncalgonized samples. Results of metal-foil expts. in Winchester show that in artificial waters Calgon promoted metal pick-up, whereas in natural waters it is deterrent. Tests carried out to det. percentage of metaphosphate remaining as such after storing water in glass bottles with air-tight stoppers. Found that large percentage remained in soln. For periods of over 4 wk. 75% remained in form of Calgon. Investigation using water contg. 30 ppm. free CO_2 showed that when sufficient lime water had been added to remove CO_2, dose of 0.5 ppm. of Calgon sufficient to prevent after-deposition of chalk and to maint. stability for 1 wk. Tests show that one part of 10% Calgon soln. added to two parts of std. Nessler soln. gives good results in detection of ammonia, namely full color and absence of deposit. In order to minimize overheating of diesel engine caused by deposition of chalk from cooling

water it can be calgonized. During $2\frac{1}{2}$ yr. Calgon treatment of cooling water has been in use, jackets free from scale and no trouble from overheating experienced. At water treatment plant chlorine residual recorder operates on o-t. photo-elec. cell principle. Difficulty experienced because flow of o-t. soln. through fine capillary tube interrupted owing to formation of minute crystals, probably o-t. hydrochloride. Following introduction of Calgon in o-t. soln. no recurrence of failure of instrument so that there appear to be good prospects that Calgon should be effective in "threshold" action on number of chems. *Discussion. Ibid.* **48**: 263 (June '45) A. H. WADDINGTON: Thomas Graham, who discovered sodium hexametaphosphate, not an Englishman. Born in Glasgow, educated at Glasgow Univ. and appointed Prof. of Chemistry at Royal Technical College, Glasgow. Sodium hexametaphosphate not used in water works field until about '37. Earliest, if not first, supply to be treated with Calgon was at Wayland, R.D.C., at Bury's Hall pumping station, Old Buckenham, Norwich. Calgon used successfully for reducing pptn. from water used for dissolving ammonia gas for chloramine treatment and has been used for preventing pptn. of solns. of sodium hypochlorite when dild. with water. In certain types of water increased eff. achieved by adding Calgon to dilg. water rather than to strong hypochlorite. J. H. T. STILGOE: Bids for softening plant called for by Mid-Wessex Water Co. in '39. Use of CO_2 specified for removing causticity and preventing afterpptn. At that time Calgon brought to company's notice. War broke out almost as soon as contract placed. Bldgs. had to go forward without waiting for tests of Calgon. Bldgs. planned for CO_2 app. and erected but completion much delayed by war. By Jan. '43 more had been learned of advantages of Calgon. Considered advisable to try Calgon without recarbonation. Plant started May 5, '44, with Calgon dose of 2.0 ppm. Two wk. later dose reduced to between 1.0 and 1.2 ppm. because of leaks in pump packing apparently due to removal of iron deposits. After 6 mo. with that dose no visible deposit in clear water tank at softening plant or service reservoirs. Costs of CO_2 plant probably would be £500 now and of Calgon app. in '43 was £165. Reagents for CO_2 process, assuming coke to be £3 10*s* per ton, and working on basis of guarantee of 0.12 lb. per 1000 gal. (Imp.), cost of coke per 1000 gal.(Imp.) water treated would be 0.06*d*. In case of Calgon, for which company paid £97 per ton, assuming dose of 0.5 ppm., cost would be 0.05*d* per 1000 gal.(Imp.). With CO_2 plant cost of steam or other power for injection had to be borne in mind. When using coke one had to deal with coking and ashing and handling of fuel, whereas Calgon need be handled only once daily. Calgon likely to cost no more than coke; it saves labor and power, requires no special bldg. and promises to be installed easily. A. E. RAWSON: One of disadvantages of lime-softened water is tendency to deposit chalk in distr. system. This led to treatment with CO_2. Treatment suffers from serious defects. Next possibility is employment of sulfuric acid. Method of treatment with Calgon very simple. Calgon does not prevent pptn. of chalk in suspension. Sodium hexametaphosphate does not necessarily give promising results even with waters of similar constitution. Each water should be treated on its merits. While true that sewage has high content of free ammonia and that free ammonia content of water sometimes rises with increased poln., erroneous to assume that these facts can serve as basis for estg. bact. contamn. J. E. COPPOCK: Calgon used in phosphatase test for detection of heat-treated milk and is acquiring many uses in clinical pathology. Delicacy of Calgon in ammonia Nessler test for detection of poln. in raw water far less than 1–2000 given by authors. Sensitivity of this test for presence of crude sewage approx. 1–700. This test given as possible alternative for detection of sewage poln. Chem. records show to date that on no occasion would estn. of free ammonia content by Calgon-Nessler test have demonstrated presence of sewage poln. Another limitation of ammonia Nessler test is that soln. required is poisonous. It is satd. soln. of periodide of mercury in strong caustic soda. R. F. LOWE: East Surrey Co. softens its chalk water by Clark's process. Mains in vicinity of works became coated with hard chalk deposit. Necessary to clean out Venturi throats every 6 mo. and centrifugal pumps every 9 mo. In '33, decided to install carbonating plant. Nuisance to operate from start. Cost was about 7*s* per mil.gal. (Imp.). In '40 Calgon used instead, and Calgon plant installed in '41. Rate of dose was about 0.25 ppm., cost being about 2*s* per mil.gal.(Imp.). Experience has been that Calgon is excellent means of stabilizing lime-softened chalk water. G. U. HOUGHTON:

Two different theories postulated to explain "calgonization." For low concns. of metaphosphate we have phys. theory in which it is assumed that pptn. prevented by some sort of colloidal action; for higher concns. calcium said to be "sequestered" in soluble complex compd. Possible that phys. interpretation is true one for whole range of concns. and that colloidal effects responsible for failure of usual chem. tests of calcium ions. With regard to direct test for ammonia authors' remarks need qualification. J. H. T. Griffiths: Most important advantage of Calgon is that it can prevent scale-forming characteristic of water at high temp. which may be balanced at relatively low temp. in way which is not feasible with CO_2. Calgon used in this way should be added after filtration. Authors' description of Langelier index liable to be misleading. Negative index mentioned as indicating water to be supersatd. in respect to chalk, which is reverse of Langelier notation. Scale removal by Calgon more likely to be due to attack on metal by Calgon rather than to dissolving of scale itself. Does not appear to be at all certain that Calgon treatment will reduce corrosion compared to that occurring with same water uncalgonized, and indications are that Calgon relatively ineffective at higher pH values. Next point that appears to require investigation is value of combined Calgon and lime treatment in insuring pptn. of protective coating throughout greater lengths of main than would be possible with lime treatment alone. No mention made in paper of variations in temp. which occurred during tests. This would have had bearing on amt. of deposition in uncalgonized samples. Some evidence that Calgon will hold iron in soln. but indications are that it must be added before water has picked up oxygen. *Authors' reply:* Several contributors questioned value of soap test. Mg almost entirely absent from raw well waters of company so that one important item against soap test does not arise. Contact time of few minutes with Calgon all that is necessary with type of water used. Authors never said Calgon-Nessler test was to displace bact. examn. Calgon-Nessler test addnl. test. Not possible to devise test for albuminoid ammonia comparable with Calgon-Nessler test. Whether Calgon has to be administered before or after filtration has to be decided for each case.—*H. E. Babbitt.*

An Automatic Control for Lime-Soda Water Softening. F. A. Champion. J. Soc. Chem. Ind. (Br.). **63**: 204 ('44). Author describes expts. which show how measurement of hardness and rate of flow of raw water, by means of conductivity cell, can be employed for automatic control of lime-soda process of water softening. Method suitable when raw water consists of variable mixt. of different types of water each of which relatively const. in compn. Quant. of reagents required per gal. of raw water has shown that rate of flow of raw water may be measured by noting effect of variable level of water above weir on resistance of specially designed conductivity cell. If electrodes of this cell suitably shaped, it may be used to measure both hardness and rate of flow. By means of thermionic relay, incorporating device which will make correction for variations in temp., elec. current passing through dual-purpose conductivity cell used to operate solenoid, which in turn controls mech. valve regulating addn. of softening reagents. No actual water softening expts. or large-scale trials of this proposed method have been made.—*W.P.R.*

Experiences in Operation of Plants for Removal of Carbonates by the Wirbos Process. A. Splittgerber. Water. *A Yearbook for Water Chemistry and the Technic of Water Treatment.* **XV** ('41–'42). Verein Deutscher Chemiker. Verlag Chemie, G.m.b.H. (Ger.) ('42) 368 pp. Wirbos process for softening water described. Diagram given of plant for production of boiler feedwater in which Wirbos process combined with base-exchange softening. Results of treatment by Wirbos process given for 2 plants in which bicarbonates removed from water to be used as make-up for boilers. First plant, which operates continuously, has capac. of 45 cm./hr. Raw water has total hardness of 14° to 28° (Ger.) and carbonate hardness of 8° to 20° (Ger.). During most of year total hardness about 23° (Ger.) and carbonate hardness about 15° (Ger.). Water softened to carbonate hardness of 1.5° to 2.5° (Ger.); pH value of softened water 9.0 to 9.8. Contact material quartz sand of 0.2-mm. diam. During first 6 wk. of operation raw water turbid; removal of bicarbonate satisfactory but treated water not clear. Second plant operates only during day and has capac. of 15 cm./hr. Munic. supply contg. large amts. of carbonate soft-

ened to carbonate hardness of 2° (Ger.). Contact material consists of small granules of marble. Increase in size of granules did not necessitate removal of any of contact material in this plant. After operation for 700 hr., however, softened water turbid and for this reason part of contact material removed. Part of softened water used for cooling oil; since introduction of Wirbos plant cooling surfaces have ceased to become encrusted.—*W.P.R.*

The Soviet Unit for Measuring Hardness of Water. V. N. ZAGRAYZKIN. Teplo-Silovoe Khoz. (U.S.S.R.) **10**: 54 ('40); Khim. Ref. Zhur. (U.S.S.R.) **4**: 6: 100 ('41). Soviet unit of hardness of water equivalent to 1 mg. of calcium per l. of water proposed. New unit will simplify designation of hardness of soft water; simple conversion factor will facilitate detn. of qual. of water by titration. —*W.P.R.*

Base Exchange of Crystalline Silicates. STERLING B. HENDRICKS. Ind. Eng. Chem. **37**: 625 ('45). Concepts for interpretation of mechanism of base exchange presented with at. diagrams for which original must be consulted. Those cryst. silicates having considerable activity have either framework or sheetlike structure. Zeolites depend on neg. portions in lattice framework and multiconnected voids large enough for ionic migration. Metal: SiO_2 ratio approaches unity when addnl. neg. groups replace water in voids. Clays and other micaceous silicates have sheetlike structures. Here external cations required to give microscopic neutrality. With montmorillonite types these principally on cleavage surfaces, with kaolin types on lateral surfaces. In glauconite and illite, which are micaceous, both types contribute to cation exchange.—*C.A.*

Cation Exchange at High pH. RAYMOND NELSON & HAROLD F. WALTON. J. Phys. Chem. **48**: 406 ('44). In order to test theory that increased uptake of Ca^{++} ions from Ca-salt soln. with increasing pH by Zeo-Karb might be due to absorption of $CaOH^+$ ions, measurements made on uptake of K ions, which do not occur as complex cations, by Zeo-Karb from solns. of pH 3.8–12.5. As with Ca, almost linear increase of uptake with pH found. This suggests that increasing Ca exchange not due to absorption of $CaOH^+$. Also indicates that Zeo-Karb contains weak acidic groups with dissociation const. of order of 10^{-13}. Probably phenolic hydroxyls whose acidity depressed by sulfonate or carboxylate radicals in same molecule. Measurements on uptake of Ni, Cu and Zn from ammoniacal salt solns. indicate that Cu absorbed principally as $Cu(NH_3)_2^{++}$, Ni as $Ni(NH_3)_4^{++}$ and Zn as complex or complexes of intermediate compn.—*C.A.*

The Determination of Hardness in Water Softened With Soda or Soda-Containing Softeners. KRISTEN BO. Kem. Maanedsblad (Denmark) **24**: 152 ('43); Chem. Zentr. (Ger.) **I**: 176 ('44). Following method recommended: 100-ml. sample of water treated with 15 ml. of soap soln. (contg. Na oleate, since soaps of satd. fatty acids not suitable) and then neutralized with 0.5 N HCl. After addn. of 15 ml. of $MgCl_2$ soln. having hardness of 240°, mixt. well shaken and filtered. HCl added to 100 ml. of filtrate, which then heated to drive off CO_2. Soln. then adjusted to phenolphthalein end point and finally titrated with 0.1 N K palmitate soln. to red tint. Hardness in degrees given by formula $H = a \times 2.8(1.3 + 0.02\ S) - k$, in which a = ml. K palmitate soln., S = ml. 0.5 N HCl and k is const. Value of k can be detd. by making detns. on 2 samples of water. First detn. carried out in accordance with method of Blache and Leicks. In second detn. 15 ml. of Na oleate added as above, then about 0.25 g. of soda (crystals), mixt. neutralized, then $MgCl_2$ added and detn. continued as above. Comparative detns. showed new method to give satisfactory values which agreed particularly well with results obtained by method of Boutron and Boudets.—*C.A.*

The Future of the Lime-Soda Water Softening Process. ANON. Engineering (Br.) **159**: 176 (Mar. 2, '45). *Report of lecture by W. F. Gerrard before Assn. British Chem. Mfrs.* Lime-soda method still most widely used process because of cheapness and simplicity. Fundamental difficulty is residual hardness which may persist several days. Expedients used to speed process include: heating incoming water, use of lime and soda in excess of strict chem. equivalent, and addn. of coagulants. Recently attention paid to catalytic action, e.g., causing water to flow through zones of pre-formed sludge. Root of process is to convert all calcium into carbon-

ate and magnesium into magnesium hydroxide, in which forms they are removed. Not good practice to ppt. carbonate and hydroxide simultaneously from same soln. When cold lime-soda process proved unsatisfactory invariably found that raw water contained both calcium and magnesium hardness. Hence 2-stage process has been built up in which lime first added, interval allowed for pptn. and coagulation, soln. filtered, and soda then added. Time required still 48 hr. Process briefly summarized: Water treated with satd. lime water to theoretical excess of 100 ppm., as $CaCO_3$, over amt. required by temporary hardness and magnesium compds. Water stirred gently for 30 min. and allowed to stand for another 30 min. when clear water drawn off and tested for alky. Sodium bicarbonate and sodium carbonate, required to destroy excess lime and remove permanent hardness, introduced and water stirred gently and settled for 30 min. Total softening time, exclusive of filtration, 2 hr. Magnesia valuable for removal of silica from water. Conditions which govern pptn. of silica with magnesium hydroxide not yet clearly understood. Tests must be extended to more types of water. Example of calcns. involved in use of lime, sodium bicarbonate and sodium carbonate, according to new technic, together with figures for orthodox practice, show, per 1000 gal. (Imp.), water contg. 275 ppm. temporary hardness, 210 ppm. permanent hardness, 345 ppm. calcium hardness and 140 ppm. magnesium hardness; use of 3.81 lb. lime, 1.01 lb. $NaHCO_3$ and 1.80 lb. Na_2CO_3. Cost would be 4.2*d* per 1000 gal. (Imp.). In orthodox procedure lime requirements are 3.06 lb. and soda 2.24 lb., costing 3.6*d* per 1000 gal.(Imp.). If comparison made with hot-process sodium-aluminate softening, new technic would be considerably more economical. Water treated by 2-stage method and with paper pulp as catalyst and filtering medium in both stages softened to 27 ppm. as $CaCO_3$ in 30 min. Same water treated with lime and soda simultaneously retained 200 ppm. hardness after 30 min. and after 2 hr. residual exceeded 100 ppm. Advantages claimed for process, for which patent application has been made, are: (1) hardness reduced to within 10 ppm. of theoretical min.; (2) silica reduced to low figure; (3) alky. of treated water could be anything one likes to make it—residual alky. independent of softening process; (4) performance achieved in cold without use of chem. coagulants and applicable to all kinds of water; (5) because of short reaction period plant is relatively small; (6) component parts can be fabricated and supplied from stock; (7) unit constr. enables customer to adapt installation to changes in water demand; (8) only 2 daily tests to be made and chart can show reagent quants. lighter than required; (9) overhauls, maint. and repairs would be lighter than usual cumbersome lime-soda plant. Process has not yet reached pilot installation stage. Risk of caustic embrittlement occurring is result of not maintg. correct boiler water condition. Caustic soda can be produced in boiler even though it has not been used. Since any kind of soda alkali, except sodium phosphate, finished eventually in boiler as caustic soda, care must be taken to avoid excess alky. in boiler water. No std. figure for allowable limit for caustic alky.—*H.E. Babbitt.*

Compressed Air Is Utilized in Water Purification. A. J. Nauta. W. W. Eng. **96**:678 ('43). Use of compressed air to remove dissolved iron from water and to improve washing of sand filters described. At one plant water required for cooling taken from artesian well. Temp. of water low but contains 23.5 ppm. dissolved Fe and 72.0 ppm. free CO_2. CO_2 displaced and dissolved Fe pptd. by aeration with compressed air in wooden aeration tank. Before use water passes to 2 filters contg. sand and gravel. Filtered water contains 0.4–0.5 ppm. iron. After year, no deposits or scale found in piping. Filters washed with water and compressed air. Violent agitation completely removes solid matter and considerably reduces amt. of wash water required. Compressed air may also be used to remove CO_2 from softened water and to maintain correct ratio of sulfate to carbonate required in boiler water.—*C.A.*